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SEPARATION OF SULPHUROUS COMPOUNDS IN SYNTHETIC CRUDE FRACTION

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Final Report

by

GEOTECHnical resources ltd.

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EXECUTIVE SUMMARY

The results of the flow studies are presented in Section 5.0 with the sulphur loading data presented in Table 5.18.

Of the underivatized ion exchange resins; IRN-77, IRN-78, IR-124, IR-130C, XAD-2, XAD-7, XAD-8 and IRN-78 the most significant sulphur loading was by IRN-78 at 6.16 mgS/g sorbent followed by XAD-7 at 3.08 mgS/g sorbent and XAD-2 at 2.30 mgS/g sorbent. The remaining resins had less than 1 mgS/g sorbent loading. Of these resins, only IRN-78 is anionic in nature, the rest are cationic. The most strongly retained species are those which have ionizable sulphur groups; cyclohexanethiol, thiophenol, butanethiol and thiocresol, a result due to the anionic nature of the ionized species.

For Amberlyst XN-1010, the highest sulphur loading was obtained with those derivatives involving metals which can form stable sulphides; copper, iron and mercury and to a lesser extent titanium and zinc. The sulphur loading for the copper derivative was 6.92 mgS/g of sorbent, iron was 6.42 mgS/g of sorbent, and mercury was 5.05 mgS/g of sorbent.

For Amberlyst 15, the highest sulphur loading was again obtained with those derivatives involving metals which can form stable sulphides; copper and iron, and to a lesser extent zinc. The absence of mercury may be due to low mercury loading on the resin. The sulphur loading for the copper derivative was 7.09 mgS/g of sorbent while iron was 4.89 mgS/g of sorbent.

For Attapulgite, the metal derivatives studied can form stable sulphides and sulphur loading was observed with copper, mercury, iron, zinc and nickel, in descending order. The sulphur loading for the copper derivative was 14.43 mgS/g of sorbent, iron is 4.15 mgS/g of sorbent and mercury 4.43 mgS/g of sorbent.

For the pillared Attapulgite Chlorhydrol, the metal derivatives studied can again form stable sulphides and sulphur loading was observed with copper, iron, mercury and zinc in descending order. Attapulgite Chlorhydrol displayed a sulphur loading somewhat less than the iron derivative and the nickel derivative displayed little loading. The sulphur loading for the copper derivative is 11.11 mgS/g of sorbent while iron is 4.82 mgS/g of sorbent.

For Bentonite, the metal derivatives studied can form stable sulphides and sulphur loading was observed with copper, iron, zinc and nickel in descending order. The sulphur loading for the copper derivative is 4.93 mgS/g of sorbent while iron is 3.37 mgS/g of sorbent.

For pillared Bentonite Chlorhydrol, the metals studied can form stable sulphides and sulphur loading was observed with copper, iron and zinc, in descending order. As with the Attapulgite Chlorhydrol, the nickel derivative did not display significant sulphur loading. The sulphur loading for the copper derivative is 4.77 mgS/g of sorbent while iron is 2.56 mgS/g of sorbent.

For Calcium Montmorillonite, sulphur loading was observed with the iron, nickel, copper, zinc and mercury derivatives, in descending order. Note the reversal of copper and iron in this case. The sulphur loading for the iron derivative is 4.24 mgS/g of sorbent, nickel is 3.88 mgS/g sorbent and copper is 3.67 mgS/g of sorbent.

For Calcium Montmorillonite Chlorhydrol, sulphur loading was observed for the copper, iron, nickel, zinc and mercury derivatives, in descending order. The copper loading is 6.54 mgS/g of sorbent and the iron is 5.47 mgS/g of sorbent.

The only zeolite sorbent with significant loading was the copper derivative preconditioned at 300 C. The loading is 7.28 mgS/g of sorbent.

For the Activated Carbon, the 6-15 mesh has a loading of 8.54 mgS/g of sorbent while the 50-200 mesh has a loading of 12.78 mgS/g of sorbent.

The ten highest sulphur loadings observed are summarized as:

Attapulgite Copper	14.43 mgS/g of sorbent
Activated Carbon 50-200 Mesh	12.78 mgS/g of sorbent
Attapulgite Chlorhydrol Copper	11.11 mgS/g of sorbent
Activated Carbon 6-15 Mesh	8.54 mgS/g of sorbent
Zeolite X-13 Copper @ 300 C	7.28 mgS/g of sorbent
Amberlyst 15 Copper	7.09 mgS/g of sorbent
Amberlyst XN-1010 Copper	6.92 mgS/g of sorbent
Calcium Montmorillonite Chlorhydrol Copper	6.54 mgS/g of sorbent
Amberlyst XN-1010 Iron	6.42 mgS/g of sorbent
Amberlite IRN-78	6.16 mgS/g of sorbent

SOMMAIRE

Les résultats des essais sont rapportés dans la Section 5.0 dont notamment le tableau 5.18 ou figurent respectivement les quantités de soufre retenu selon les adsorbants testés.

Parmi les résines échangeur d'ions Amberlite, non-dopées de métaux, IRN-77, IRN-78, IR-124, IR-130C, XAD-2, XAD-7 et XAD-78, celle qui retint la plus grande quantité de l'élément soufre fut la IRN-78 avec 6,16 mg de S/g d'adsorbant. La résine XAD-7 retint 3,08 mg de S/g d'adsorbant et la résine XAD-2 retint 2,30 mg de S/g d'adsorbant. Toutes les autres resines ont adsorbé moins de 1 mg de S/g de résine. Toutes les résines sont cationiques sauf la IRN-78, celle qui donna le meilleur résultant, qui est anionique. Les produits les plus fortement adsorbés furent les thiols ou mercaptans, comme le cyclohexanethiol, le thiophenol, le butanethiol ou le thiocrésol, dont le groupe fonctionnel a une forte tendance a s'ioniser et former des anions thiolates se comportant comme un réactif nucléophile susceptible d'effectuer des réactions de substitution sur le substrat fixe de la résine.

Avec la résine Amberlyst XN-1010, la meilleure rétention de soufre fut obtenue avec ses dérivés enrichis de métaux tels que le cuivre, le fer et le mercure, lesquels sont susceptibles de former des sulfures stables. Le dérivé au cuivre retint 6,92 mg de S/g d'adsorbant, celue au fer 6.42 mg de S/g d'adsorbant et celue au mercure 5,05 mg de S/g d'adsorbant. Des résultats plus modérés furent obtenus avec le titane et le zinc.

Avec la résine Amberlyst 15, la meilleure rétention de soufre fut aussi obtenue grâce aux dérivés dopés de métaux capables de former des sulfures stable. Le dérivé au cuivre retint 7,09 mg S/g d'adorbant et celui au fer 4,89 mg de S/g d'adsorbant. Un résultat modéré fut obtenu avec le dérivé au zinc. Le dérivé au mercure ne donna pas de résultat satisfaisant á cause de la difficulté á mélanger le mercure á cette résine.

Avec l'attapulgite, la rétention de soufre fut obtenue avec un dopage aux métaux formant des sulfures stables dans l'ordre decroissant suivant: cuivre, mercure, fer, zinc et nickel. Le dérivé au cuivre retint 14,43 mg de S/g d'adsorbant, celui au mercure 4,43 mg de S/g d'adsorbant et celui au fer 4,15 mg de S/g d'adsorbant.

Avec l'attapulgite dont la structure interstitielle a été renforcee au Chlorhydrol, les dérivés enrichis de métaux ont formé et retenu des sulfures dans l'ordre suivant: cuivre, fer, mercure et zinc. Toutefois, par rapport au cas sans traitement au chlorhydrol, la rétention du dérivé au cuivre a diminué á 11,11 mg de S/g d'adsorbant, celle du dérivé au mercure est devenue moindre que celle du dérivé au fer qui a monté légèrement a 4,82 mg de S/g d'adsorbant, et celle du dérivé au nickel est devenue quasiment insignifiante.

Avec la bentonite, la rétention de soufre fut obtenue avec un dopage aux métaux formant des sulfures stables dans l'ordre decroissant suivant: cuivre, fer, zinc et nickel. Le derive au cuivre retint 4,93 mg de S/g d'adsorbant et celui au fer 3,37 mg de S/g d'adsorbant.

Avec la bentonite dont la structure interstitielle a été renforcée au Chlorhydrol, les dérivés enrichis de métaux ont formé et retenu des sulfures dans l'ordre suivant: cuivre, fer et zinc. La rétention du dérivé au cuivre fut de 4,77 mg de S/g d'adsorbant et celle du fer 2,56 mg de S/g d'adsorbant. Comme pour le cas de l'attapulgite traitée au chlorhydrol, la rétention de soufre par le dérivé au nickel fut tout aussi insignifiante.

Avec la montmorillonite de calcium, la rétention de soufre fut observée avec des dérivés dopes de métaux dans l'ordre suivant: fer, nickel, cuivre, zinc et mercure. On remarquera dans ce cas que le fer a pris la première place hatituellement attribuée au cuivre. La rétention du dérivé au fer fut de 4,24 mg de S/g d'adsorbant, celle du nickel 3,88 mg de S/g d'adsorbant et celle du cuivre 3,67 mg de S/g d'adsorbant.

Avec la montmorillonite de calcium renforcée au Chlorhydrol, les dérivés enrichis de métaux ont retenu des sulfures dans l'ordre suivant: cuivre, fer, nickel, zinc et mercure. La rétention du dérivé au cuivre fut de 6,54 mg de S/g d'adsorbant et celle du fer 5,47 mg de S/g d'adsorbant.

Avec la zéolite, la seule adsorption notable fut avec un dérivé enrichi au cuivre et préconditionné a 300 C. La rétention de ce dérivé au cuivre fut de 7,28 mg de S/g d'adsorbant.

Avec le charbon actif, on a observé une rétention de 8,54 mg de S/g d'adsorbant de maille 6-15, et une rétention de 12,78 mg de S/g d'adsorbant de maille 50-200.

Les dix meilleures rétentions de soufre sont récapitulees comme suit:

1	Attapulgite au cuivre	14,43 mg de S/g d'adsorbant
2	Charbon actif, maille 50-200	12,78 mg de S/g d'adsorbant
3	Attapulgite au Chlorhydrol et	11,11 mg de S/g d'adsorbant
4	Charbon actif, maille 6-15	8,54 mg de S/g d'adsorbant
5	Zeolite X-13 au cuivre et a 300 C	7,28 mg de S/g d'adsorbant
6	Amberlyst 15 au cuivre	7,09 mg de S/g d'adsorbant
7	Amberlyst XN-1010 au cuivre	6,92 mg de S/g d'adsorbant
8	Montmorillonite de calcium au Chlorhydrol et au cuivre	6,54 mg de S/g d'adsorbant
9	Amberlyst XN-1010 au fer	6,42 mg de S/g d'adsorbant
10	Amberlite IRN-78	6,16 mg de S/g d'adsorbant

1.0 INTRODUCTION

This document forms the final report regarding **Proposal 14.SQ.23440-5-9136, SEPARATION OF SULPHUROUS COMPOUNDS IN SYNTHETIC CRUDE FRACTION.**

The proposed research required the selection of ten organosulphur compounds representative of the sulphurous constituents of crude oil, the development of gas chromatographic methodology for the separation and quantitation of these compounds in a toluene matrix, and the evaluation of a variety of sorbents for their efficiency in removing the sulphurous constituents from a synthetic crude oil mixture. Sorbents which were evaluated include: zeolites, activated carbon, clay minerals, cation exchange resins, anion exchange resins and organoselective adsorption resins. Cation exchangers including zeolites, clays and resins were evaluated using a variety of metals as the exchangeable cation. Sorbents were also characterized in terms of surface area and elemental composition where applicable.

2.0 PHASE 1: SELECTION OF ORGANOSULPHUR COMPOUNDS, DEVELOPMENT OF GAS CHROMATOGRAPHIC METHODOLOGY AND PREPARATION OF THE SYNTHETIC CRUDE OIL MIXTURE

2.1 SELECTION OF ORGANOSULPHUR COMPOUNDS

A wide variety of organosulphur compounds have been identified in various crude oils. In the low to medium molecular weight fraction of crude oils (up to C-25); thiols, sulphides, disulphides, thiophenes, benzothiophenes, dibenzothiophenes and napthobenzothiophenes have been identified(1,2,3). Maturation of crude oil increases the quantity of thiophenic sulphur, while nonthiophenic sulphur is more abundant in immature crudes(4). Elemental sulphur may also occur in crude oils formed at temperatures below 100 C(5). High molecular weight sulphur heterocycles occur in the resin and asphaltene fractions of crudes in association with oxygen and nitrogen.

Based upon the following screening criteria, and the desire to employ compounds representative of those found in oils, twenty organosulphur compounds analogous to those nitrogenous compounds included in a previous study (6), were selected for potential use in the synthetic crude oil:

i. Sufficiently different chromatographic retention times to allow chromatographic resolution and quantitation of each component.

ii. Maximization of the range of chemical and physical properties.

iii. Solubility in toluene and compatibility with other solutes.

iv. Commerical availability and purity of reagents.

v. Safety considerations.

The compounds which were initially selected are presented in Table 2.1. From this group, in consultation with the Scientific Authority, Pierre Chantal, ten compounds which provide a range of boiling points, molecular weights, branching, cyclization, aromaticity and percentage of sulphur were selected for use in the synthetic crude oil mixture. The selected compounds, which are presented in Table 2.2, were obtained from Aldrich Chemical and Pfaltz & Bauer Inc. and are as pure as commercially available, typically greater than 99.5% pure.

2.2 GAS CHROMATOGRAPHIC EQUIPMENT AND DEVELOPMENT OF THE GAS CHROMATOGRAPHIC METHODOLOGY

The chromatographic equipment consists of a Shimadzu GC-9A gas chromatograph with a SPL-G9 split/splitless injector, flame ionization detection and a AOC-9 automatic sample injector. Since the study involves quantitation of only the specific organosulphur compounds in the synthetic crude, it is possible to use a flame ionization detector rather than a sulphur specific flame photometric detector. The chromatographic system was coupled to a Varian Vista 601 data station for data integration and quantitation.

A test solution containing each of the organosulphur compounds at approximately 250 ppm sulphur in toluene was prepared for use in developing the chromatographic procedure. Chromatographic experience suggested that the ten test compounds could be separated and quantitated on an SE-30 capillary column with temperature programming, which proved to be the case. The resulting chromatographic conditions are presented in Table 2.3. The chromatographic run time was 11.1 minutes with a cycle time, including oven cool down, of 23.0 minutes.

2.3 PREPARATION OF SYNTHETIC CRUDE OIL MIXTURE

Prior to preparation of the synthetic crude oil test mixture, test runs were made using thiocresol and two of the sorbents; calcium-montmorillonite and amberlyst 26, to establish an appropriate sulphur loading which would result in a reasonable breakthrough volume for the various organosulphur components in the synthetic crude mixture. From these tests it was concluded that an appropriate concentration level would be such that each of the ten organosulphur compounds contributed 100 ppm sulphur to the mixture, for a total sulphur loading of 1,000 ppm. The synthetic crude oil mixture was then prepared by dissolving appropriate weights of each organosulphur compound in ultrapure toluene.

To confirm the chromatographic instrumental linearity of response, standards of 10, 20, 50 and 100 ppm sulphur in each of the ten test compounds were analyzed. The results are presented in Table 2.4. Inspection of these data indicate that the response is linear up to at least 100 ppm for each of the test compounds. Ten replicate analyses of the 100 ppm standard were undertaken to establish the accuracy and precision of the chromatographic system. These results are presented in Table 2.5 as the average value and standard deviation of the replicate determinations on each of the ten components in the synthetic crude mixture.

TABLE 2.1: Organosulphur Compounds Initially Selected for Potential Use in the Synthetic Crude Oil Mixture.

- Butanethiol
- Hexadecyl Mercaptan
- p-Dithiane
- Benzyl Mercaptan
- 3-Methylthiophene
- Thianaphthene
- Thianthrene
- Octanethiol
- Butylsulphide
- Thiophenol
- Thiocresol
- 2-Thienylbutane
- Dibenzothiaphene
- Butyldisulphide
- Decanethiol
- Cyclohexanethiol
- Thioanisole
- Thiophene
- 2,2'-Bithiophene
- Diphenylsulphide

TABLE 2.2: Organosulphur Coumpounds Selected for Use in the Synthetic Crude Oil Mixture.

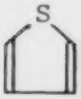
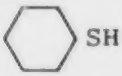
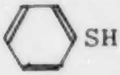
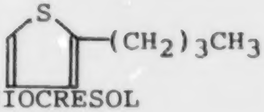
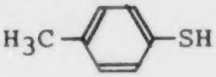
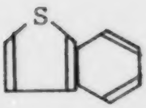
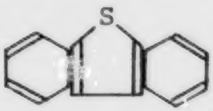
COMPOUND	MOLECULAR WEIGHT (grams)	SULPHUR (wt%)	BOILING POINT (C)
THIOPHENE 	84.14	38.10	84
BUTANETHIOL $CH_3(CH_2)_3SH$	90.19	35.55	98
CYCLOHEXANETHIOL 	116.23	27.58	158
THIOPHENOL 	110.18	29.10	169
2-THIENYLBUTANE 	140.26	22.86	
THIOCRESOL 	124.21	25.81	
BUTYLSULPHIDE $CH_3(CH_2)_3S(CH_2)_3CH_3$	146.30	21.91	188
THIANAPHTHENE 	134.20	23.89	221
BUTYLDISULPHIDE $CH_3(CH_2)_3SS(CH_2)_3CH_3$	178.36	17.97	229
DIBENZOTHIAPHENE 	184.26	17.40	332

TABLE 2.3: Chromatographic Conditions

Column:	SE-30, 15 m length, 0.25 mm ID 0.25 micron coating thickness
Detector:	Flame Ionization Detector
Injector/Detector Temperature	360 C
Split Ratio:	70:1
Injection Volume:	5 uL
Initial Temperature:	80 C
Temperature Program:	Initial hold 2.5 minutes 10 C/minute to 110 C, 0.1 minute hold 30 C/minute to 260 C, 1.0 minute hold
Carrier Gas Flow Rate:	1.1 mL/minute

TABLE 2.4: Four Point Calibration Data for the Ten Organosulphur Test Compounds.

COMPOUND	10 ppm	20 ppm	50 ppm	100 ppm
THIOPHENE	9.9	20.0	51.1	99.2
BUTANETHIOL	10.0	20.1	50.5	100.6
CYCLOHEXANETHIOL	10.1	19.6	50.1	100.3
THIOPHENOL	9.7	19.7	49.8	100.3
2-THIENYLBUTANE	9.6	20.0	50.2	100.8
THIOCRESOL	10.2	19.9	50.7	101.6
BUTYLSULPHIDE	10.1	19.8	50.0	100.7
THIANAPHTHENE	9.9	20.6	49.3	100.6
BUTYLDISULPHIDE	10.0	20.1	49.6	99.8
DIBENZOTHIAPHENE	9.5	19.9	50.2	101.0

TABLE 2.5: Average and Standard Deviation for Ten Replicate Analyses of the Synthetic Crude Oil Mixture.

COMPOUND	AVERAGE	STANDARD DEVIATION
THIOPHENE	99.2	2.4
BUTANETHIOL	100.6	1.2
CYCLOHEXANETHIOL	100.3	1.7
THIOPHENOL	100.3	2.6
2-THIENYLBUTANE	100.8	2.4
THIOCRESOL	101.6	2.6
BUTYLSULPHIDE	100.7	2.4
THIANAPHTHENE	100.6	2.4
BUTYLDISULPHIDE	99.8	2.5
DIBENZOTHIAPHENE	101.0	2.4

3.0 PHASE 2: PREPARATION AND CHARACTERIZATION OF SORBENTS

The sorbents, as specified in the proposal, were obtained from BDH Chemicals with the exception of the clays which were obtained from the Clay Minerals Society, Source Clay Minerals Repository, Department of Geology, University of Missouri, Columbia, Missouri.

3.1 ZEOLITES X, Y AND MORDENITE

Commercial sources of Zeolite Y and mordenite could not be located and hence these sorbents were eliminated from the study.

Zeolite X-13 was acquired and included in the study. Forty gram portions of Zeolite X-13 were subjected to cation exchange with H^+, Zn(II), Ca(II), Cu(II) and Hg(II) as their chloride salts. The cation exchange solutions consisted of 1 N hydrochloric acid and 10 grams per liter aqueous concentrations of the divalent cations. The exchange was performed in glass chromatography columns by flowing 200 mL of the cation solutions through the zeolite bed by gravity feed at a rate of approximately 1 mL/min. The resulting five sorbents were divided into two 20 gram portions, one fraction was dehydrated at 300 C and the other at 500 C prior to testing. This procedure resulted in the preparation of 10 sorbents.

3.2 CLAYS AND PILLARED CLAYS

The following clays were acquired for testing: Ca-montmorillonite, attapulgite, bentonite, nontronite and vermiculite. Two of the clays, nontronite and vermiculite, were not available in pure form. An attempt was made to purify the nontronite after the wet sedimentation method described by Schneiderhoehn (7). However, XRD analysis of the nontronite after several attempts indicated it was only about 40% pure. As a consequence, nontronite was eliminated from the study. Individuals at the Source Clay Minerals Repository suggested that the vermiculite could be purified by hand picking. However, the vermiculite particles in the sample were extremely small and hand picking was not feasible. Since no other source of pure vermiculite could be found, vermiculite was eliminated from the study.

Twenty gram portions of the remaining three clays were cation exchanged with Zn(II), Ni(II), Cu(II), Fe(III) and Hg(II) by stirring with 200 mL of 10 grams per liter solutions of the cations as their chloride salts. The slurries were stirred for one hour at 90 C, filtered, washed and oven dried at 105 C. When preparation of the Hg(II) form of bentonite was attempted the clay displayed severe swelling such that the solution volume in which the derivative was being prepared had to be more than doubled to prevent solidification of the sorbent mixture. However, the preparation was carried to completion and the Hg(II)-bentonite derivative was submitted for surface area determination and elemental analysis. However insufficient sample was recovered for inclusion in the flow studies. This procedure resulted in the preparation of fifteen sorbents, fourteen of which were included in the flow studies.

Attapulgite, Ca-montmorillonite and bentonite pillared clays were prepared after the procedure of Occelli and Tindwa (8). Twenty grams of each clay were slurried in demineralized water to which 30 meq of chlorhydrol had been added. The slurries were stirred at 90 C for one hour, filtered, washed and dried at 105 C. As was the case with the Hg(II)-bentonite derivative, the bentonite chlorhydrol slurry displayed severe swelling during preparation. This derivative was submitted for surface area determination and elemental analysis, but was not included in the flow study because of the small amount of sample recovered. This procedure resulted in the preparation of three sorbents, two of which were included in the flow study.

The above procedure was repeated on separate twenty gram portions of Ca-montmorillonite, bentonite and attapulgite with the addition of the aforementioned exchangeable cations. The clays were slurried in 10 grams per liter aqueous solutions of the cations as their chloride salts. This was followed by the addition of chlorhydrol, stirring for one hour at 90 C, filtration, washing and drying at 105 C. As was the previous case, the Hg(II)-bentonite derivative displayed severe swelling. This derivative was submitted for surface area determination and elemental analysis but was not included in the flow studies because of the small amount of sample which was recovered. This procedure resulted in the preparation of fifteen sorbents, of which fourteen were included in the flow studies.

During preparation of the pillared clays, there did not appear to be any physical change in the appearance of the clays. The pillared clay preparation was repeated twice with the same result. A comparison of the surface areas of the pillared and unpillared clays, Table 4.1, indicates that there is little difference in the surface areas of the pillared and unpillared clays. The experiments of Occelli and Tindwa (8) utilized sodium montmorillonite, which had been previously studied and was known to undergo reaction with chlorhydrol. The crystalline structure of sodium montmorillonite can have 1, 2, 3 or more layers per unit cell, with inter-layer spacings of 12.5, 15.5 or 19 A, respectively. This is in comparison to calcium montmorillonite, studied here, which has two layers per unit cell with spacing of 15.5 A. The inter-layer spacing of these clays varies from 10 to 21 A depending upon the cation and the extent of hydration. Hence, the variations in the crystal lattice, as noted, between the sodium form, as studied by Occelli and Tindwa, and the calcium form studied here, may be sufficient to preclude interaction with the chlorhydrol molecule which must enter the inter-layer void to effect swelling. Conversely, the inter-layer spacing of the calcium form may be large enough to allow the chlorhydrol to enter without dramatically affecting the inter-layer spacing.

3.3 ION EXCHANGE AND ADSORPTION RESINS

The ion exchange resins XN1010, Amberlyst 15, Amberlyst 26, XAD-2, XAD-7, XAD-8, IRN-77, IRN-78, IR-124 and IR-130C were obtained for study. The resins were dry packed in the HPLC column for testing. Prior to testing, the resins were conditioned by upward flow of three bed volumes each of methanol and toluene.

The XAD-2, XAD-7 and XAD-8 polystyrene and acrylic ester polymeric sorbents were rinsed with deionized water, methanol and toluene prior to testing to remove any excess reactants and/or materials formed or leached from the resin during storage.

The IRN-78 nuclear grade divinylbenzene-polystyrene copolymer with quaternary amine functional groups was acquired in the hydroxide form. Twenty grams of the resin was contacted with 200 mL of 1 N aqueous potassium hydroxide in a glass chromatography column and then rinsed with deionized water, methanol and toluene to remove impurities. The sorbent was dry packed and conditioned as outlined above.

Two hundred twenty grams of Amberlyst 15 cation exchange resin was washed four times with 10% w/w potassium hydroxide in methanol in a glass chromatography column, rinsed with methanol and Soxhlet extracted for 24 hours with methanol. The resin was activated by cautious addition to a stirred 10% solution of hydrochloric acid in methanol, followed by distilled water washing to neutral pH and 24 hour Soxhlet extraction with methanol, benzene and pentane. The resin was dried for 24 hours at 40 C. Twenty grams of the resin remained in the hydrogen form and 20 gram portions were converted to Zn(II), Cu(II), Hg(II), Fe(III), Ni(II), Sr(II), Ba(II), La(III), Ti(III) and V(III) forms using a glass chromatography column and 10 grams per liter aqueous solutions of the cations as their chloride salts in a manner analogous to that described above for the zeolites. While V(IV) was to have been used, it could not be obtained as the chloride salt and V(III) was substituted. This procedure yielded 11 sorbents. Each was dry packed into the HPLC column as outlined above.

The Amberlyst 26 anion exchange resin was washed four times with 10% v/v hydrochloric acid in methanol followed by distilled water until the effluent was neutral. The resin was activated using 10% w/w potassium hydroxide in methanol and washed with distilled water to neutral pH. The resin was Soxhlet extracted for 24 hours each with methanol and benzene, dried at 40 C and dry packed as outlined above.

The cation exchange resins IRN-77, IR-124 and IR-130C were converted to their hydrogen form. Twenty grams of each resin were contacted with 200 mL of 1 N hydrochloric acid followed by rinses with deionized water, methanol and toluene and were dried at 40 C for 24 hours. Each was dry packed into the HPLC column as outlined above.

The XN1010 cation exchange resin was converted to its hydrogen form by contacting 220 grams of the resin with 2,000 mL of 1 N hydrochloric acid followed by rinses with deionized water, methanol and toluene and drying at 40 C for 24 hours. Twenty gram portions of resin were then put into their Zn(II), Cu(II), Hg(II), Fe(III), Ni(II), Sr(II), Ba(II), La(III), Ti(III) and V(III) forms as outlined above. This procedure yielded eleven sorbents. Each was dry packed into an HPLC column as outlined above.

In total 30 resins were prepared for testing.

3.4 ACTIVATED CARBON

In consultation with the Scientific Authority, two types of activated carbon were selected for testing, coconut charcoal 6-15 mesh and coconut charcoal 50-200 mesh. In preparation for testing, 20 grams of each activated carbon were rinsed with deionized water, methanol and toluene and oven dried at 105 C. They were dry packed for testing.

In total, 75 sorbents were prepared for testing.

4.0 PHASE 3: SORBENT CHARACTERIZATION

Characterization of the sorbents consisted of determining the surface area and elemental composition of each.

The BET specific surface areas were determined by nitrogen adsorption-desorption by the Quantachrome Corporation of Anaheim, California. In regard to the zeolites, Quantachrome was limited, by equipment constraints, to a maximum preconditioning temperature of 400 C. Hence, the zeolite surface areas were determined at 300 C and 400 C rather than 300 C and 500 C. Results of those determinations are presented in Table 4.1.

The elemental composition of the zeolites, clays and pillared clays were determined by inductively coupled plasma emission spectroscopy. The sorbents were fused with hydroxide/peroxide, acidified, filtered and diluted to an appropriate volume for analysis. Sodium, aluminum, silicon, zinc, calcium, copper and mercury were determined in the zeolites, aluminum, silicon, iron, magnesium, zinc, nickel, copper and mercury in the clays and pillared clays. Results of these analyses are presented in Table 4.2.

TABLE 4.1: SORBANT SINGLE POINT SURFACE AREAS

Sorbant	Weight (grams)	Total Surface Area (m2)	Specific Surface Area (m2/g)
XN1010			
H	0.0305	13.22	433.44
Zn	0.0746	26.20	351.21
Cu	0.0648	23.21	358.18
Hg	0.0561	23.07	411.23
Fe	0.0727	24.58	338.10
Ni	0.0697	24.85	356.53
Sr	0.5815	190.71	327.96
Ba	0.0857	26.16	305.25
La	0.0795	24.77	311.57
Ti	0.0908	31.27	344.38
V	0.1006	34.04	338.37
Amberlyst 15			
H	0.1963	9.94	50.64
Zn	0.0734	2.70	36.79
Cu	0.3081	11.39	36.97
Hg	0.3450	12.76	36.99
Fe	0.2056	9.23	44.89
Ni	0.0735	2.65	36.05
Sr	0.3402	13.30	39.10
Ba	0.2637	9.67	36.67
La	0.2241	9.08	40.52
Ti	0.1062	4.60	43.32
V	0.4314	20.21	46.85
Amberlyst 26	0.2072	7.58	36.58
XAD-2	0.1843	60.33	327.35
XAD-7	0.0625	28.48	455.68
XAD-8	0.0849	8.66	102.00
IRN-77	0.7362	0.07	0.10
IRN-78	0.7907	0.09	0.11
IR-124	0.7572	0.008	0.01
IR-130C	0.5324	0.02	0.04

TABLE 4.1: SORBANT SINGLE POINT SURFACE AREAS

Sorbant	Weight (grams)	Total Surface Area (m2)	Specific Surface Area (m2/g)
Zeolite X-13 @ 300°C			
H	0.3310	17.96	54.26
Zn	0.4943	53.74	108.72
Ca	0.4434	46.29	104.40
Cu	0.1852	1.84	9.94
Hg	0.3152	2.91	9.23
Zeolite X-13 @ 400°C			
H	0.5224	119.33	228.43
Zn	0.5268	100.56	190.89
Ca	0.3113	12.36	39.70
Cu	0.6511	6.41	9.84
Hg	0.5991	5.16	8.61
Bentonite			
Zn	0.5346	17.52	32.77
Ni	0.9776	23.20	23.73
Cu	0.4786	13.79	28.81
Fe	0.4664	15.10	32.38
Hg	0.5035	10.30	20.48
Bentonite-Chlorhydrol			
Zn	0.5558	19.80	35.62
Ni	0.3110	8.28	26.62
Cu	0.4391	10.00	22.77
Fe	0.4506	14.75	32.73
Hg	0.3905	6.19	15.85
Bentonite Chlorhydrol	0.3513	8.43	23.00
Attapulgite Chlorhydrol	0.1340	27.67	206.49
Ca-Montmorillonite Chlorhydrol	0.2729	17.80	65.22
Attapulgite			
Zn	0.3170	42.79	134.98
Ni	0.2456	39.94	162.62
Cu	0.2666	51.53	193.29
Fe	0.2093	34.48	164.74
Hg	0.3303	69.42	210.17

TABLE 4.1: SORBANT SINGLE POINT SURFACE AREAS

Sorbant	Weight (grams)	Total Surface Area (m2)	Specific Surface Area (m2/g)
Attapulgite-Chlorhydrol			
Zn	0.1122	19.78	176.29
Ni	0.2297	41.17	179.23
Cu	0.2795	41.28	147.69
Fe	0.1311	15.02	114.59
Hg	0.1519	28.99	190.85
Ca-Montmorillonite			
Zn	0.4507	31.86	70.69
Ni	0.5775	40.44	70.03
Cu	0.6546	39.51	60.36
Fe	0.3730	28.44	76.25
Hg	0.6846	35.39	51.69
Ca-Montmorillonite-Chlorhydrol			
Zn	1.0289	60.95	59.24
Ni	0.0947	6.28	66.31
Cu	0.8678	58.88	67.85
Fe	0.7524	48.48	64.43
Hg	0.7079	48.43	68.41
Activated Charcoal			
6-15 mesh	0.0470	36.67	780.21
50-200 mesh	0.0382	50.99	1334.82

TABLE 4.2: ELEMENTAL COMPOSITION OF THE ZEOLITES, CLAYS AND PILLARED CLAYS

Sorbent	ELEMENTAL COMPOSITION, WT% Al	Ca	Cu	Fe	Hg	Mg	Ni	Si	Zn
Bentonite									
Cu	8.06		2.61	2.79	0.0	1.10	0.04	25.53	0.13
Fe	7.68		0.02	6.41	0.0	1.03	0.23	23.68	0.01
Hg	7.63		0.02	2.58	1.99	1.23	0.02	25.26	0.01
Ni	7.86		0.02	2.67	0.0	1.09	2.36	24.06	0.02
Zn	8.26		0.02	2.50	0.0	1.04	0.04	26.65	2.59
Bentonite Chlorhydrol									
Neat	8.76		0.02	2.75	0.0	1.16	0.01	27.19	0.0
Cu	9.41		2.64	2.79	0.0	1.07	0.06	26.71	0.0
Fe	9.45		0.06	6.48	0.0	1.10	0.06	27.80	0.0
Hg	9.94		0.04	3.64	2.02	1.02	0.07	26.61	0.01
Ni	9.53		0.02	2.67	0.0	1.08	2.13	26.32	0.02
Zn	9.80		0.03	2.70	0.0	1.19	0.07	27.16	2.19
Attapulgite									
Cu	4.71		0.99	2.46	0.0	5.34	0.02	23.56	0
Fe	4.80		0.0	3.86	0.0	4.73	0.08	25.29	0.0
Hg	4.80		0.0	2.29	0.30	5.05	0.05	23.98	0.0
Ni	4.63		0.0	2.06	0.0	4.39	0.86	24.27	0.0
Zn	4.93		0.01	2.20	0.0	5.07	0.03	24.26	0.85
Attapulgite Chlorhydrol									
Neat	4.79		0.01	2.48	0.0	5.53	0.14	23.73	0.0
Cu	5.52		1.42	2.09	0.0	4.24	0.82	24.66	0.02
Fe	5.01		0.01	1.98	0.0	4.24	0.82	24.66	0.02
Hg	5.34		0.02	2.04	0.0	4.39	0.36	25.80	0.0
Ni	5.34		0.04	2.14	0.0	4.77	1.00	24.27	0.01
Zn	5.03		0.03	2.61	0.0	4.01	0.08	24.98	0.88

TABLE 4.2: ELEMENTAL COMPOSITION OF THE ZEOLITES, CLAYS AND PILLARED CLAYS

Sorbent	ELEMENTAL COMPOSITION, WT%								
	Al	Ca	Cu	Fe	Hg	Mg	Ni	Si	Zn
Zeolite X-13 300°C									
Ca	15.44	7.50	0.03		0.0			19.24	0.0
Cu	14.12	0.02	9.54		0.0			16.60	0.0
H	14.73	0.52	0.0		0.0			20.71	0.0
Hg	14.57	0.06	0.02		1.48			18.02	0.0
Zn	16.23	0.01	0.02		0.0			18.81	4.68
Zeolite X-13 500°C									
Ca	12.69	6.39	0.01		0.0			17.56	0.0
Cu	14.87	0.04	7.20		0.0			17.06	0.02
H	15.12	0.04	0.01		0.0			19.94	0.0
Hg	14.44	0.01	0.05		0.96			18.26	0.0
Zn	13.58	0.14	0.02		0.0			18.18	7.43
Calcium Montmorillonite									
Cu	7.49		2.46	1.02	0.0	3.16	0.12	23.02	0.0
Fe	7.12		0.07	4.94	0.0	3.06	0.11	22.58	0.0
Hg	7.75		0.06	0.97	0.0	3.58	0.09	23.07	0.0
Ni	6.53		0.08	0.87	0.0	2.84	2.09	19.55	0.0
Zn	7.69		0.04	1.03	0.0	3.19	0.09	23.06	2.49
Calcium Montmorillonite Chlorhydrol									
Neat	10.20		0.04	1.17	0.0	3.92	0.05	26.77	0.02
Cu	8.40		2.43	1.09	0.0	3.23	0.09	23.65	0.02
Fe	7.97		0.04	6.41	0.0	3.42	0.06	24.39	0.00
Hg	8.58		0.05	1.04	0.0	3.72	0.05	25.60	0.01
Ni	8.84		0.04	0.99	0.0	3.05	2.32	23.06	0.02
Zn	8.73		0.05	1.06	0.0	3.21	0.09	22.97	2.38

5.0 PHASE 4: EVALUATION OF THE SORBENTS WITH THE MODEL SOLUTION

The high pressure liquid chromatographic system used in the model solution flow experiments is illustrated schematically in Figure 5. The system consists of a solvent reservoir, a Gilson Model 302 high performance liquid chromatographic pump, a 30 cm long X 0.4 cm ID stainless steel column packed with sorbents and configured for upward flow and an LKB Ultrorac 7000 fraction collector. A differential pressure gauge was installed between the top and the base of the column to monitor the pressure drop across the packed column. The back pressures are noted for those cases where a significant pressure drop occurred.

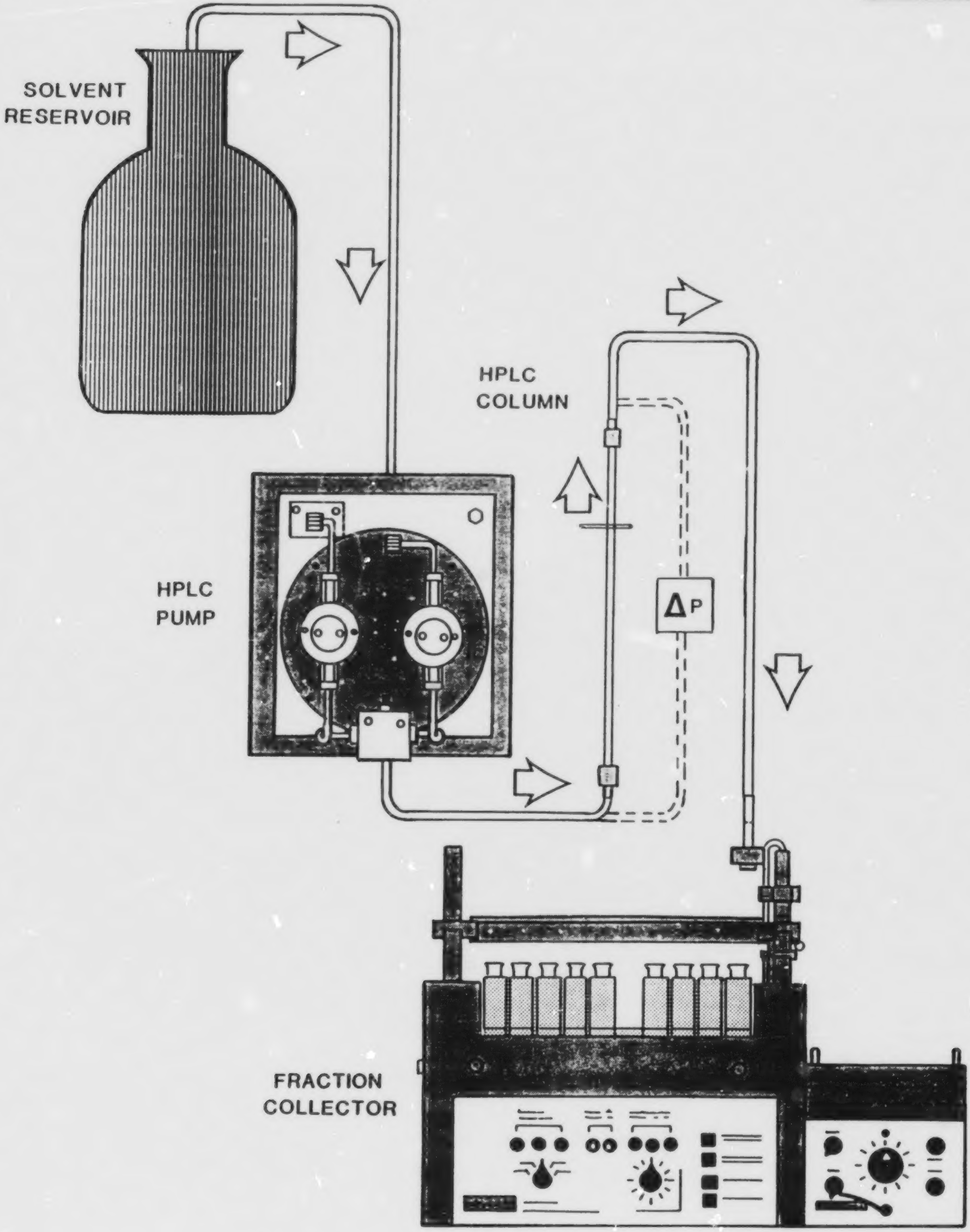
Sorbents were dry packed in the HPLC column using standard procedures for liquid chromatography (9). Solvents used in column conditioning and the synthetic crude oil mixture were vacuum degassed and ultrafiltered using membrane filters prior to introduction into the fluid flow system to prevent erratic flow behavior and column plugging during the flow experiments. The sorbents were preconditioned, as outlined in Sections 3.1 to 3.4, prior to initiating the synthetic crude oil mixture flow.

For the purpose of this study, the expression "dead volume" has been defined as the volume of the packed column which is not occupied by the sorbents. This method does not discriminate between intra- and interparticle space, but simply determines the total void space in the column. For each of the 75 sorbent packed columns, the bed volume was determined by the volume of toluene required to fill the void space and reach the top of the column.

The synthetic crude oil mixture was pumped in an upward flow direction through the packed column at a constant flow rate of approximately 5 bed volumes per hour for a total of approximately 25 bed volumes throughput. Five milliliter fractions of the effluent were collected for chromatographic analysis using the methodology and calibration curves developed in Section 2.2. Pump performance, fraction collector performance and differential pressure were closely monitored throughout the flow experiments.

From the results of gas chromatographic analysis, flow rates, sorbent bed volumes and the flow system dead volume, breakthrough curves (Ci/Co versus volume) were plotted for each of the ten components in the synthetic crude oil mixture for each of the sorbents tested. These plots are presented below along with the discussion of the results.

The Ci/Co values which comprise the breakthrough curves were determined by dividing the chromatographically determined concentrations of each component by the concentration of that component in the synthetic crude oil mixture, which is nominally 100 ppm in sulphur.


SOLVENT RESERVOIR
HPLC COLUMN
HPLC PUMP
ΔP
FRACTION COLLECTOR

SCHEMATIC DIAGRAM OF HIGH PRESSURE LIQUID CHROMATOGRAPHIC FLOW SYSTEM

The sulphur loading on each sorbent was determined by integrating the area above the Ci/Co plot for each component and summing up the sulphur loading due to each component to obtain the overall loading. For this purpose, all the Ci/Co data from the start to the end of each flow study was utilized. Although the flow experiments involved flowing 25 bed volumes of synthetic crude oil mixture over each sorbent, the absolute volume of crude oil mixture utilized varies because the sorbent bed volumes vary from 4.9 mL for Amberlite IR-124 to 9.4 mL for attapulgite mercury derivative. This is of no consequence for those sorbents for which solute breakthrough is complete within the 25 bed volume duration of the experiment. However, for those sorbents for which the solute breakthrough is not complete, the sulphur loadings are underestimated and are not directly comparable since the sorbents are exposed to differing volumes of the crude oil mixture.

Data resulting from the flow experiments are presented in both tabular and graphical forms as Ci/Co versus throughput volume for each of the sorbents tested. For those cases in which the Ci/Co plots for several components are very similar, only a single component is plotted to simplify the appearance of the plots. The sulphur loading on each sorbent is summarized in Table 5.18.

5.1 Amberlite IRN-77

Amberlite IRN-77 is a strongly acidic nuclear grade cation exchange resin with a minimum exchange capacity in the hydrogen form of 1.8 meq/mL. The BET specific surface area of this resin was determined to 0.10 square meters per gram. The primary application is cationic decontamination of by-pass coolant streams in nuclear reactors.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.1 and Figure 5.1. The thiophene chromatographic peak is strongly overlapped by the chromatographic peak due to methanol used in preconditioning the sorbent. Since the elution profiles are very similar for all the components, only a single Ci/Co profile has been plotted. Examination of the data indicates that solute breakthrough occurred within 30 mL throughput, 5.5 bed volumes, with none of the components being strongly retained by the IRN-77 resin. This is as expected since none of the test organosulphur compounds are strongly basic and hence would not exist as cations in the test solution.

The sulphur loading on this sorbent is 9.40 mgS, or 0.97 mgS/g of sorbent.

5.2 Amberlite IRN-78

Amberlite IRN-78 is a strongly basic quaternary ammonium nuclear grade anionic exchange resin with a minimum exchange capacity of 1.2

meq/mL. The resin was tested in its hydroxide form. The BET specific surface area was determined to be 0.11 square meters per gram. The primary application is anionic decontamination of by-pass coolant streams in nuclear reactors.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.2 and Figure 5.2. The thiophene chromatographic peak is strongly overlapped by the chromatographic peak due to methanol used in preconditioning the sorbent. The results for thiophene are presented in Table 5.2 but are not included in the sulphur loading calculations. Since the elution profiles are very similar for several components, only selected Ci/Co profiles have been plotted. This ionic exchange resin would be expected to retain anionic species generated by acidic dissociation of the solute. Examination of the data indicates that butylsulphide, thianaphthene, butyldisulphide and dibenzothiaphene, which have no ionizable sites, were not strongly retained by the resin. Complete breakthrough of 2-thienylbutane occurred after 10 bed volumes, cyclohexanethiol after 16.6 bed volumes while butanethiol, thiophenol and thiocresol, the most acidic of the test compounds, still had a Ci/Co equal to zero after 25 bed volumes throughput.

The sulphur loading on this sorbent is 48.97 mgS, or 6.16 mgS/g of sorbent.

5.3 Amberlite IR-124

Amberlite IR-124 is a strongly acidic cation exchanger with sulfonic acid functionality and a minimum exchange capacity of 2.2 meq/mL. The resin was tested in the hydrogen form. The BET specific surface area was determined to be 0.01 square meters per gram. Typical commercial applications of this resin are in recovery of metals from chrome plating baths and rinse waters.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.3 and Figure 5.3. The thiophene chromatographic peak is strongly overlapped by the chromatographic peak due to methanol used in preconditioning the sorbent. Since the elution profiles are very similar for all the components, only a single Ci/Co profile has been plotted. Examination of the data indicates that complete solute breakthrough occurred within 30 mL throughput, 6.1 bed volumes. This is as expected since none of the test organosulphur compounds are strongly basic and hence would not exist as cations in the test solution.

The sulphur loading on this sorbent is 9.20 mgS, or 0.89 mgS/g of sorbent.

5.4 Amberlite IR-130C

Amberlite IR-130C is a strongly acidic cation exchanger with sulfonic acid functionality and a minimum exchange capacity of 1.9 meq/mL. The resin was tested in the hydrogen form. The BET specific surface area was determined to be 0.04 square meters per gram. Typical commercial applications of this resin are in high flow rate condensate polishing.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.4 and Figure 5.4. The thiophene chromatographic peak is strongly overlapped by the chromatographic peak due to methanol used in preconditioning the sorbent. Since the elution profiles are very similar for all the components, only a single Ci/Co profile has been plotted. Examination of the data indicates that complete solute breakthrough occurred within 30 mL throughput, 4.8 bed volumes, with none of the components being strongly retained by the IR-130C resin. This is as expected since none of the test organosulphur compounds are strongly basic and hence would not exist as cations in the test solution.

The sulphur loading on this sorbent is 6.84 mgS, or 0.69 mgS/g of sorbent.

5.5 Amberlite XAD-2

Amberlite XAD-2 is a polystyrene polymeric adsorbent with a typical surface area of 300 square meters per gram, which compares well with the experimental BET specific surface area of 327.35 square meters per gram, average pore diameter of 90 angstroms and 42% porosity. The primary application of this sorbent is in phenol and organic removal and recovery of antibiotics from flowing streams.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.5 and Figure 5.5. The thiophene chromatographic peak is strongly overlapped by the chromatographic peak due to methanol used in preconditioning the sorbent. Since the elution profiles are very similar for all the components, only a single Ci/Co profile has been plotted. Examination of the data indicates that complete solute breakthrough occurred within 35 mL throughput, 4.3 bed volumes.

The sulphur loading on this sorbent is 10.90 mgS, or 2.30 mgS/g of sorbent.

5.6 Amberlite XAD-7

Amberlite XAD-7 is an acrylic ester polymeric adsorbent having a typical surface area of 450 square meters per gram, which compares well with the experimental BET specific surface area of 455.68

square meters per gram, average pore diameter of 90 angstroms and 55% porosity.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.6 and Figure 5.6. The thiophene chromatographic peak is strongly overlapped by the chromatographic peak due to methanol used in preconditioning the sorbent. The butanethiol peak was strongly interferred with by an anomolous chromatographic peak which appeared to originate from the amberlite XAD-7, hence the butanethiol is omitted from Table 5.6. Since the elution profiles are very similar for all the components, only a single Ci/Co profile has been plotted. Examination of the data indicates that complete solute breakthrough occurred within 40 mL throughput, 4.6 bed volumes, with none of the components being strongly retained by the XAD-7 resin. The longer elution time as compared to the XAD-2 is a consequence of the greater porosity of the XAD-7 resin.

The sulphur loading on this sorbent is 12.77 mgS, or 3.08 mgS/g of sorbent.

5.7 Amberlite XAD-8

Amberlite XAD-8 is an acrylic ester polymeric adsorbent resin with a surface area of 160 square meters per gram, which compares reasonably with the experimental BET specific surface area of 102.00 square meters per gram, average pore diameter of 225 angstroms and a porosity of 52%. The primary application is to treatment of paper pulp mill wastes.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.7 and Figure 5.7. The thiophene chromatographic peak is strongly overlapped by the chromatographic peak due to methanol used in preconditioning the sorbent. Since the elution profiles are very similar for all the components, only a single Ci/Co profile has been plotted. Examination of the data indicates that complete solute breakthrough occurred within 20 mL throughput, 2.4 bed volumes, with none of the components being strongly retained by the XAD-2 resin.

The sulphur loading on this sorbent is 8.34 mgS, or 1.86 mgS/g of sorbent.

5.8 Amberlyst XN-1010

5.8.1 Amberlyst XN-1010 Barium

XN-1010 is a cationic exchange resin. In the barium form it has an experimental BET specific surface area of 305.25 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.8.1 and Figure 5.8.1. The thiophene chromatographic peak is strongly overlapped by the chromatographic peak due to methanol used in preconditioning the sorbent and is not included in the data. Since the elution profiles are very similar for several of the components, only specific Ci/Co profiles have been plotted. Examination of the data indicates that complete solute breakthrough occurred within 20 mL throughput, 3.2 bed volumes, for 2-thienylbutane, butylsulphide, thianaphthene, butyldisulphide and dibenzothiaphene with complete breakthrough for the remaining components after 45 mL throughput, 7.3 bed volumes. The Ci/Co profile is as expected for displacement of a solute stream through a packed bed. However, early breakthrough of the larger molecular components indicates a molecular sieve effect was operating to retard the smaller molecular components.

The sulphur loading on this sorbent is 11.57 mgS, or 1.41 mgS/g of sorbent.

5.8.2 Amberlyst XN-1010 Copper

XN-1010 is a cationic exchange resin. In the copper form it has an experimental BET specific surface area of 358.18 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.8.2 and Figure 5.8.2. The thiophene chromatographic peak is strongly overlapped by the chromatographic peak due to methanol used in preconditioning the sorbent and is not included in the data. Examination of the data indicates that complete solute breakthrough occurred within 20 mL throughput, 3.2 bed volumes, for the nonionizable larger molecular components 2-thienylbutane, butylsulphide, thianaphthene, butyldisulphide and dibenzothiaphene. However, for the smaller molecular components with ionizable sulphurs; butanethiol, cyclohexanethiol, thiophenol and thiocresol there was no solute breakthrough even after 25 bed volumes, 160 mL, of the synthetic crude oil mixture had passed through the column. The retention of these components is probably due to the ability of copper to form stable sulphides.

The sulphur loading on this sorbent is 54.61 mgS, or 6.92 mgS/g of sorbent.

5.8.3 Amberlyst XN-1010 Hydrogen

XN-1010 is a cationic exchange resin. In the hydrogen form it has an experimental BET specific surface area of 433.44 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.8.3 and Figure 5.8.3. The thiophene chromatographic peak is strongly overlapped by the chromatographic peak due to methanol used in preconditioning the sorbent and is not included in the data. Examination of the data indicates that complete solute breakthrough occurred within 20 mL throughput, 3.4 bed volumes, for the nonionizable larger molecular components 2-thienylbutane, butylsulphide, thianaphthene, butyldisulphide and dibenzothiaphene. However, the smaller molecular components with ionizable sulphurs; butanethiol and cyclohexanethiol, achieved complete breakthrough after 50 mL throughput, 8.5 bed volumes, while thiophenol and thiocresol required 70 mL throughput, 11.9 bed volumes, to obtain complete breakthrough.

The sulphur loading on this sorbent is 11.89 mgS, or 1.68 mgS/g of sorbent.

5.8.4 Amberlyst XN-1010 Iron

XN-1010 is a cationic exchange resin. In the iron(III) form it has an experimental BET specific surface area of 338.10 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.8.4 and Figure 5.8.4. The thiophene chromatographic peak is strongly overlapped by the chromatographic peak due to methanol used in preconditioning the sorbent and is not included in the data. Examination of the data indicates that complete solute breakthrough occurred within 15 mL throughput, 2.5 bed volumes, for the nonionizable larger molecular components 2-thienylbutane, butylsulphide, thianaphthene, butyldisulphide and dibenzothiaphene. However, the smaller molecular components with ionizable sulphurs; butanethiol and cyclohexanethiol, achieved Ci/Co ratios of 0.27 and 0.42, respectively, after 35 mL throughput, 5.7 bed volumes, and did not increase through the remainder of the test. In the case of thiophenol and thiocresol, which are aromatic thiols with ionizable sulphurs, there was no solute breakthrough even after 25 bed volumes, 152 mL, of the synthetic crude oil mixture had passed through the column. The retention of these components is again probably due to the formation of stable sulphides with the Fe(III) bound in the resin.

The sulphur loading on this sorbent is 47.20 mgS, or 6.42 mgS/g of sorbent.

5.8.5 Amberlyst XN-1010 Lanthanum

XN-1010 is a cationic exchange resin. In the lanthanum form it has an experimental BET specific surface area of 311.57 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.8.5 and Figure 5.8.5. The thiophene chromatographic peak is strongly overlapped by the chromatographic peak due to methanol used in preconditioning the sorbent and is not included in the data. Examination of the data indicates that complete solute breakthrough for all components occurred within 30 mL throughput, 4.8 bed volumes.

The sulphur loading on this sorbent is 6.77 mgS, or 0.88 mgS/g of sorbent.

5.8.6 **Amberlyst XN-1010 Mercury**

XN-1010 is a cationic exchange resin. In the mercury form it has an experimental BET specific surface area of 411.23 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.8.6 and Figure 5.8.6. In this case, the thiophene chromatographic peak is only slightly interferred with by the chromatographic peak due to methanol used in preconditioning the sorbent and is presented in the data but not included in the loading calculation. Inspection of the data indicates complete breakthrough for thianaphthene and dibenzothiaphene after 5.3 bed volumes, while 2-thienylbutane has a quick initial breakthrough and then slowly increases to the end of the test. Butanethiol, cyclohexanethiol, thiophenol and thiocresol have slow increases through the test.

The sulphur loading on this sorbent is 39.52 mgS, or 5.05 mgS/g of sorbent.

5.8.7 **Amberlyst XN-1010 Nickel**

XN-1010 is a cationic exchange resin. In the nickel form it has an experimental BET specific surface area of 356.53 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.8.7 and Figure 5.8.7. The thiophene chromatographic peak is strongly overlapped by the chromatographic peak due to methanol used in preconditioning the sorbent and is not included in the data. Inspection of the data indicates complete solute breakthrough for 2-thienylbutane, butylsulphide, thianaphthene, butyldisulphide and dibenzothiaphene at 4.0 bed volumes, for cyclohexanethiol and thiocresol at 4.8 bed volumes and thiophenol at 5.6 bed volumes. The Ci/Co increases more slowly for butanethiol and reaches 1.0 after 10.5 bed volumes. As in previous studies, XN-1010 is a cationic exchange resin and, under the experimental conditions, none of the synthetic crude oil components would be cationic. In this case, nickel does not form stable enough sulphides to retain the sulphur components.

The sulphur loading on this sorbent is 10.50 mgS, or 1.47 mgS/g of sorbent.

5.8.8 **Amberlyst XN-1010 Strontium**

XN-1010 is a cationic exchange resin. In the strontium form it has an experimental BET specific surface area of 327.96 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.8.8 and Figure 5.8.8. The thiophene chromatographic peak is strongly overlapped by the chromatographic peak due to methanol used in preconditioning the sorbent and is not included in the data. Examination of the data indicates that complete solute breakthrough for all components occurred within 35 mL throughput, 6.0 bed volumes.

The sulphur loading on this sorbent is 12.29 mgS, or 1.62 mgS/g of sorbent.

5.8.9 **Amberlyst XN-1010 Titanium**

XN-1010 is a cationic exchange resin. In the titanium form it has an experimental BET specific surface area of 344.38 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.8.9 and Figure 5.8.9. The thiophene chromatographic peak is strongly overlapped by the chromatographic peak due to methanol used in preconditioning the sorbent and is not included in the data. Examination of the data indicates that complete solute breakthrough for the larger components with no ionizable sulphurs; 2-thienylbutane, butylsulphide, butyldisulphide and dibenzothiaphene, occurred at 20 mL throughput, 3.3 bed volumes. Cyclohexanethiol was complete at 30 mL, 4.9 bed volumes, which indicates slight solute retention. Thiophenol breakthrough was complete at 45 mL, 7.4 bed volumes, indicating somewhat greater retention, while butanethiol and thiocresol were complete at 55 mL, 9.0 bed volumes.

The sulphur loading on this sorbent is 13.04 mgS, or 1.74 mgS/g of sorbent.

5.8.10 **Amberlyst XN-1010 Vanadium**

XN-1010 is a cationic exchange resin. In the vanadium form it has an experimental BET specific surface area of 338.37 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.8.10 and Figure 5.8.10. The thiophene chromatographic peak is strongly overlapped by the chromatographic peak due to methanol used in preconditioning the sorbent and is not included in the data. Examination of the data indicates that for the larger components having no ionizable sulphurs; 2-thienylbutane, butylsulphide, thianaphthene, butyldisulphide, dibenzothiaphene, and in this case cyclohexanethiol, complete solute breakthrough occurred within 25 mL throughput, 4.6 bed volumes. Breakthrough for thiophenol and thiocresol occurred at 45 mL throughput, 8.2 bed volumes, and for butanethiol at 55 mL throughput, 10 bed volumes.

The sulphur loading on this sorbent is 15.54 mgS, or 2.07 mgS/g of sorbent.

5.8.11 Amberlyst XN-1010 Zinc

XN-1010 is a cationic exchange resin. In the zinc form it has an experimental BET specific surface area of 351.21 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.8.11 and Figure 5.8.11. The thiophene chromatographic peak is strongly overlapped by the chromatographic peak due to methanol used in preconditioning the sorbent and is not included in the data. Inspection of the data indicates 2-thienylbutane, butylsulphide, thianaphthene, butyldisulphide and dibenzothiaphene have completely broken through after 40 mL throughput volume, 4.4 bed volumes. Butanethiol, thiophenol, cyclohexanethiol and thiocresol reach essentially complete breakthrough later in the test.

The sulphur loading on this sorbent is 13.98 mgS, or 2.09 mgS/g of sorbent.

5.9 Amberlyst 15

Amberlyst 15 is a strongly acidic cation exchange resin with sulphydro functionality. The resin has a nominal surface area of 50 square meters per gram, porosity of 36%, minimum exchange capacity of 4.7 meq/mL and an average pore diameter of 240 angstroms. The resin is useful in nonaqueous ion exchange systems for removal of cationic and basic impurities. The primary application is as a nonaqueous catalyst. Catalytic activity is seriously degraded by exchange of cationic metals. The resin will swell 10-15% in toluene.

5.9.1 Amberlyst 15 Barium

In the barium form the resin has an experimental BET specific surface area of 36.67 square meters per gram which is somewhat lower than the nominal value.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.9.1 and Figure 5.9.1. The thiophene chromatographic peak is strongly overlapped by the chromatographic peak due to methanol used in preconditioning the sorbent and is not included in the data. Examination of the data indicates that complete solute breakthrough has occurred for all component species within 25 mL throughput, 4.4 bed volumes.

The sulphur loading on this sorbent is 11.74 mgS, or 1.52 mgS/g of sorbent.

5.9.2 Amberlyst 15 Copper

In the copper form the resin has an experimental BET specific surface area of 36.97 square meters per gram which is somewhat lower than the nominal value.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.9.2 and Figure 5.9.2. Thiophene is somewhat interfered with by the chromatographic peak due to methanol used in preconditioning the sorbent, data is presented in Table 5.9.2 but is not included in the sulphur loading calculations. Examination of the data indicates that those components not having ionizable sulphurs; thiophene, 2-thienylbutane, butylsulphide, thianaphthene, butyldisulphide and dibenzothiaphene, have complete solute breakthrough after approximately 25 mL throughput, 4.3 bed volumes. Those test components having ionizable sulphurs display significant retention. Butanethiol reaches a Ci/Co of approximately 0.20 which remains essentially constant throughout the 150 mL throughput, 25.8 bed volumes. The remaining three components; cyclohexanethiol, thiophenol and thiocresol, have no solute breakthrough at the completion of the test, 25.8 bed volumes throughput. This is probably a consequence of the ability of copper to form stable sulphides, thus retaining the ionized species.

The sulphur loading on this sorbent is 54.94 mgS, or 7.09 mgS/g of sorbent.

5.9.3 Amberlyst 15 Iron

In the iron form the resin has an experimental BET specific surface area of 44.89 square meters per gram which is only 10% lower than the nominal value.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.9.3 and Figure 5.9.3. Thiophene is strongly overlapped by the chromatographic peak due to methanol used in preconditioning the sorbent and is not is included in Table 5.9.3. In this case, dibenzothiaphene, which is overlapped by a broad chromatographic peak not previously observed, has also been omitted. Examination of the data indicates that those components not having ionizable sulphur display early breakthrough. Butyldisulphide at 30 mL, 5.0 bed volumes, 2-thienylbutane, butylsulphide and thianaphthene at 50 mL, 10 bed volumes. Butanethiol and cyclohexanethiol reach a maximum Ci/Co of 0.63 and 0.77, respectively, while thiophenol and thiocresol reach a maximum Ci/Co of only 0.13 and 0.10, respectively after 25 bed volumes throughput. This is probably a consequence of the formation of stable iron sulphide complexes thus retaining the ionized species.

The sulphur loading on this sorbent is 35.42 mgS, or 4.89 mgS/g of sorbent.

5.9.4 Amberlyst 15 Hydrogen

In the hydrogen form the resin has an experimental BET specific surface area of 50.64 square meters per gram which is in excellent agreement with the nominal value of 50 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.9.4 and Figure 5.9.4. In this case the thiophene chromatographic peak is only slightly interferred with by the chromatographic peak due to methanol used in preconditioning the sorbent and is included in the data. Examination of the data indicates that complete solute breakthrough has occurred for all component species within 35 mL throughput, 5.5 bed volumes.

The sulphur loading on this sorbent is 12.34 mgS, or 1.82 mgS/g of sorbent.

5.9.5 Amberlyst 15 Lanthanum

In the lanthanum form the resin has an experimental BET specific surface area of 40.58 square meters per gram which is about 20% lower than the nominal value.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.9.5 and Figure 5.9.5. The thiophene chromatographic peak is strongly overlapped by the chromatographic peak due to methanol used in preconditioning the sorbent and is not included in the data. Examination of the data indicates that complete solute breakthrough has occurred for all component species within 30 mL throughput, 5.1 bed volumes.

The sulphur loading on this sorbent is 10.26 mgS, or 1.41 mgS/g of sorbent.

5.9.6 Amberlyst 15 Mercury

In the mercury form the resin has an experimental BET specific surface area of 36.99 square meters per gram which is 26% lower than the nominal value.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.9.6 and Figure 5.9.6. The thiophene chromatographic peak is strongly overlapped by the chromatographic peak due to methanol used in preconditioning the sorbent and is not included in the data. Examination of the data indicates that, with the exception of butanethiol which required 45 mL throughput, 7.8 bed volumes, complete solute breakthrough has occurred for all component species within 35 mL throughput, 6.0 bed volumes.

The sulphur loading on this sorbent is 13.12 mgS, or 1.79 mgS/g of sorbent.

5.9.7 Amberlyst 15 Nickel

In the nickel form the resin has an experimental BET specific surface area of 36.05 square meters per gram which is 26% lower than the nominal value.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.9.7 and Figure 5.9.7. The thiophene chromatographic peak is strongly overlapped by the chromatographic peak due to methanol used in preconditioning the sorbent and is not included in the data. Examination of the data indicates that initial breakthrough for all components begins at 2.5 bed volumes and increases to greater than 0.90 within 5.9 bed volumes.

The sulphur loading on this sorbent is 14.19 mgS, or 1.92 mgS/g of sorbent.

5.9.8 Amberlyst 15 Strontium

In the strontium form the resin has an experimental BET specific surface area of 39.10 square meters per gram which is 22% lower than the nominal value.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.9.8 and Figure 5.9.8. The thiophene chromatographic peak is strongly overlapped by the chromatographic peak due to methanol used in preconditioning the sorbent and is not included in the data. Examination of the data indicates that, with the exception of butanethiol which required 80 mL, 12.9 bed volumes, complete solute breakthrough occurred for all component species within 40 mL throughput, 6.45 bed volumes. The butanethiol plot is somewhat rounded at the top indicating a little solute retention was operating.

The sulphur loading on this sorbent is 11.70 mgS, or 1.54 mgS/g of sorbent.

5.9.9 **Amberlyst 15 Titanium**

In the titanium form the resin has an experimental BET specific surface area of 43.32 square meters per gram which is 14% lower than the nominal value.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.9.9 and Figure 5.9.9. The thiophene chromatographic peak is strongly overlapped by the chromatographic peak due to methanol used in preconditioning the sorbent and is not included in the data. Examination of the data indicates that complete solute breakthrough has occurred for all component species within 30 mL throughput, 4.8 bed volumes.

The sulphur loading on this sorbent is 11.87 mgS, or 1.67 mgS/g of sorbent.

5.9.10 **Amberlyst 15 Vanadium**

In the vanadium form the resin has an experimental BET specific surface area of 46.85 square meters per gram which is about 10% lower than the nominal value.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.9.10 and Figure 5.9.10. The thiophene chromatographic peak is strongly overlapped by the chromatographic peak due to methanol used in preconditioning the sorbent and is not included in the data. Examination of the data indicates that, with the exception of butanethiol which required 35 mL, 5.7 bed volumes, complete solute breakthrough occurred for all component species within 25 mL throughput, 4.1 bed volumes.

The sulphur loading on this sorbent is 11.14 mgS, or 1.62 mgS/g of sorbent.

5.9.11 **Amberlyst 15 Zinc**

In the zinc form the resin has an experimental BET specific surface area of 36.79 square meters per gram which is 26% lower than the nominal value.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.9.11 and Figure 5.9.11. The thiophene chromatographic peak is strongly overlapped by the chromatographic peak due to methanol used in preconditioning the sorbent and is not included in the data. Examination of the data indicates that for the larger molecular components having no ionizable sulphurs; 2-thienylbutane, butylsulphide, thianaphthene, butyldisulphide and dibenzothiaphene, complete solute breakthrough occurred within 35 mL throughput, 5.8 bed volumes.

The sulphur loading on this resin was 18.16 mgS, or 2.38 mgS/g of sorbent.

5.10 Attapulgite

5.10.1 Attapulgite Copper Derivative

The attapulgite copper derivative has an experimentally determined BET specific surface area of 193.29 square meters per gram.

The Ci/Co versus synthetic crude oil thrcughput volume data are presented in Table 5.10.1 and Figure 5.10.1. Examination of the data indicates that complete solute breakthrough occurred for thiophene after only 20 mL throughput volume, 2.2 bed volumes. In addition, by 20 mL throughput the Ci/Co values for 2-thienylbutane, thianaphthene, butyldisulphide and dibenzothiaphene have reached 0.90, although they continue to slowly increase throughout the 25 bed volumes, 230 mL, of the experiment. Butylsulphide increases sharply up to 45 mL, 4.9 bed volumes, and then increases slowly to reach 0.96 at the conclusion of the experiment. Those components having ionizable sulphurs, butanethiol, cyclohexanethiol, thiophenol and thiocresol, show no significant solute breakthrough to the conclusion of the test.

The sulphur loading on this sorbent is 117.0 mgS, or 14.43 mgS/g of sorbent.

5.10.2 Attapulgite Iron (III) Derivative

The attapulgite iron (III) has an experimentally determined BET specific surface area of 193.29 square meters per gram. The column back pressure at the start of this test was 7,580 kPa and increased to 12,400 kPa at the conclusion of the test.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.10.2 and Figure 5.10.2. Examination of the data indicates that complete solute breakthrough occurred for thiophene after only 15 mL throughput volume, 1.7 bed volumes. In addition, by 20 mL throughput the Ci/Co values for butanethiol, 2-thienylbutane, butylsulphide, thianaphthene, butyldisulphide and dibenzothiaphene are over 0.85, although they continue to slowly increase throughout the 25 bed volumes, 220 mL, of the test. Those components having ionizable sulphurs, thiophenol and thiocresol, slowly increase through the test, reaching a final Ci/Co of 0.69 and 0.55, respectively.

The sulphur loading on this sorbent is 30.82 mgS, or 4.15 mgS/g of sorbent.

5.10.3 Attapulgite Mercury Derivative

The attapulgite mercury derivative has an experimentally determined BET specific surface area of 210.17 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.10.3 and Figure 5.10.3. Examination of the data indicates that complete solute breakthrough occurred for thiophene after only 20 mL throughput volume, 2.1 bed volumes. In addition, by 25 mL throughput the Ci/Co values for 2-thienylbutane, butylsulphide, thianaphthene, butyldisulphide and dibenzothiaphene are over 0.90, although they continue to slowly increase throughout the 25 bed volumes, 235 mL, of the experiment. Butanethiol breakthrough is complete at 65 mL, 6.9 bed volumes. Initial solute breakthrough begins at 3.2 bed volumes for cyclohexanethiol, 3.7 bed volumes for thiophenol and 5.3 bed volumes for thiocresol. The Ci/Co values reach a maximum of 0.85, 0.73 and 0.70 for cyclohexanethiol, thiophenol and thiocresol, respectively.

The sulphur loading on this sorbent is 36.53 mgS, or 4.43 mgS/g of sorbent.

5.10.4 Attapulgite Nickel Derivative

The attapulgite nickel derivative has an experimentally determined BET specific surface area of 162.62 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.10.4 and Figure 5.10.4. Examination of the data indicates that complete solute breakthrough occurred for cyclohexanethiol, 2-thienylbutane, butylsulphide, thianaphthene, butyldisulphide and dibenzothiaphene after only 20 mL throughput volume, 2.2 bed volumes, butanethiol after 3.4 bed volumes and thiophene after 6.7 bed volumes. Thiophenol and thiocresol breakthrough began at 1.7 bed volumes and slowly increased to 1.0 at 11.2 and 12.3 bed volumes, respectively.

The sulphur loading on this sorbent is 14.08 mgS, or 2.10 mgS/g of sorbent.

5.10.5 Attapulgite Zinc Derivative

The attapulgite zinc derivative has an experimentally determined BET specific surface area of 134.98 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.10.5 and Figure 5.10.5. Solute breakthrough is complete for 2-thienylbutane, butylsulphide, thianaphthene, butyldisulphide and dibenzothiaphene after only 25 mL throughput volume, 3.0 bed volumes. Thiophene, butanethiol and cyclohexanethiol reach a Ci/Co greater than 0.90 after 4.2 bed volumes and remain essentially constant over the remainder of the test. Thiophenol and thiocresol breakthrough begins at 3.0 bed volumes and their Ci/Co increases slowly through the test to final values of 0.93 and 0.90, respectively.

The sulphur loading on this sorbent is 15.86 mgS, or 1.87 mgS/g of sorbent.

5.11 Attapulgite Chlorhydrol Derivative

The attapulgite chlorhydrol derivative has an experimentally determined BET specific surface area of 206.49 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.11.1 and Figure 5.11.1. With the exception of thiophenol and thiocresol, Ci/Co values for all components were greater than 0.90 after 25 mL throughput volume, 4.8 bed volumes. Breakthrough for thiophenol and thiocresol begins at 3.8 bed volumes and the Ci/Co slowly increases to 0.69 and 0.63 at the conclusion of the experiment.

The sulphur loading on this sorbent is 21.60 mgS, or 3.12 mgS/g of sorbent.

5.11.2 Attapulgite Chlorhydrol Copper Derivative

The attapulgite chlorhydrol copper derivative has an experimentally determined BET specific surface area of 147.69 square meters per gram which is considerably less than that of attapulgite chlorhydrol. The column back pressure was 14,470 kPa throughout the test.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.11.2 and Figure 5.11.2. The Ci/Co values for 2-thienylbutane, thianaphthene, butylsulphide and dibenzothiaphene were greater than 0.90 after 25 mL throughput volume, 2.7 bed volumes, and increased only slowly throughout the remainder of the test. Thiophene and butylsulphide reached a Ci/Co of 0.90 after 7.0

bed volumes and increased slowly to 1.0 after 18.8 and 9.7 bed volumes, respectively. Cyclohexanethiol, thiophenol and thiocresol showed no solute breakthrough throughout the 25 bed volumes of the test while butanethiol increased to 0.18 after 9.7 bed volumes and remained essentially constant after.

The sulphur loading on this sorbent is 87.30 mgS, or 11.11 mgS/g of sorbent.

5.11.3 Attapulgite Chlorhydrol Iron (III) Derivative

The attapulgite chlorhydrol iron (III) derivative has an experimentally determined BET specific surface area of 114.59 square meters per gram which is 44% less than that of attapulgite chlorhydrol. The initial column back pressure was 8,300 kPa and decreased to a final back pressure of 5,200 kPa.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.11.3 and Figure 5.11.3. The Ci/Co values for 2-thienylbutane, butylsulphide, thianaphthene, butylsulphide and dibenzothiaphene were greater than 0.90 after 25 mL throughput volume, 2.9 bed volumes, and remained essentially constant at approximately 0.92 throughout the remainder of the test. Thiophene and butanethiol reached complete solute breakthrough after 2.9 and 4.8 bed volumes, respectively. Cyclohexanethiol reached 0.80 after 4.0 bed volumes and increased to only 0.86. Solute breakthrough for thiophenol and thiocresol began at 2.9 bed volumes and increase slowly throughout the test to final values of 0.63 and 0.59, respectively.

The sulphur loading on this sorbent is 34.67 mgS, or 4.82 mgS/g of sorbent.

5.11.4 Attapulgite Chlorhydrol Mercury Derivative

The attapulgite chlorhydrol mercury derivative has an experimentally determined BET specific surface area of 190.85 square meters per gram which is only 9% less than that of attapulgite chlorhydrol. The initial column back pressure was 2,900 kPa and reached a final back pressure was 4,400 kPa.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.11.4 and Figure 5.11.4. With the exception of thiophenol and thiocresol, all components reached complete solute breakthrough after 30 mL throughput volume, 3.2 bed volumes. Thiophenol and thiocresol showed an initial solute breakthrough at 1.6 bed volumes and increased to final values of 0.90 and 0.87, respectively.

The sulphur loading on this sorbent is 16.95 mgS, or 2.38 mgS/g of sorbent.

5.11.5 Attapulgite Chlorhydrol Nickel Derivative

The attapulgite chlorhydrol nickel derivative has an experimentally determined BET specific surface area of 179.23 square meters per gram which is 14% less than that of attapulgite chlorhydrol. The initial column back pressure was 6,900 kPa and decreased to a final back pressure of 5,200 kPa.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.11.5 and Figure 5.11.5. Thiophene and butanethiol reached complete solute breakthrough after 2.2 and 2.8 bed volumes respectively. With the exception of thiocresol, all other components had reached a Ci/Co value greater than 0.90 after 30 mL throughput volume, 2.8 bed volumes. Thiocresol increased sharply to 0.82 at 2.8 bed volumes and increased slowly to a final value of 0.91 at the conclusion of the test.

The sulphur loading on this sorbent is 14.80 mgS, or 2.11 mgS/g of sorbent.

5.11.6 Attapulgite Chlorhydrol Zinc Derivative

The attapulgite chlorhydrol zinc derivative has an experimentally determined BET specific surface area of 176.29 square meters per gram which is 15% less than that of attapulgite chlorhydrol.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.11.6 and Figure 5.11.6. With the exception of thiophenol and thiocresol, all component had complete solute breakthrough at 30 mL throughput volume, 3.4 bed volumes. Thiophenol and thiocresol breakthrough began at 2.3 bed volumes, reached a Ci/Co value 0.80 at 3.4 bed volumes and slowly increased to final values of 0.93 and 0.89, respectively, at the conclusion of the test.

The sulphur loading on this sorbent is 15.65 mgS, or 2.25 mgS/g of sorbent.

5.12 Bentonite

5.12.1 Bentonite Copper Derivative

The bentonite copper derivative has an experimentally determined BET specific surface area of 28.81 square meters per gram which is considerably less than either of the other two clays tested.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.12.1 and Figure 5.12.1. Thiophene had complete breakthrough after 20 mL throughput volume, 3.4 bed volumes, while the Ci/Co values for 2-thienylbutane, thianaphthene, and dibenzothiaphene were greater than 0.75 and increased only slowly to reach final values of 0.82 at the conclusion of the test. Butyldisulphide breakthrough began at 2.6 bed volumes and slowly increased through the test to a final value of 0.77. Butanethiol breakthrough began at 3.4 bed volumes and remained essentially constant at 0.20 throughout the test. Butylsulphide breakthrough began at 18.1 bed volumes and increased slowly to 0.39 at 25 bed volumes. Cylcohexanethiol, thiophenol and thiocresol did not exhibit any solute breakthrough during the course of the test.

The sulphur loading on this sorbent is 75.82 mgS, or 4.93 mgS/g of sorbent.

5.12.2 Bentonite Iron (III) Derivative

The bentonite iron (III) derivative has an experimentally determined BET specific surface area of 32.38 square meters per gram which is considerably less than either of the other two clays tested.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.12.2 and Figure 5.12.2. Thiophene had complete breakthrough after 20 mL throughput volume, 3.4 bed volumes, while the Ci/Co values for 2-thienylbutane, thianaphthene, and dibenzothiaphene were greater than 0.75 and increased only slowly to reach final values of 0.82 at the conclusion of the test. Butyldisulphide breakthrough began at 2.6 bed volumes and slowly increased through the test to a final value of 0.77. Butanethiol breakthrough began at 3.4 bed volumes and remained essentially constant at 0.20 throughout the test. Butylsulphide breakthrough began at 18.1 bed volumes and increased slowly to 0.39 at 25 bed volumes. Cylcohexane thiol, thiophenol and thiocresol did not exhibit any solute breakthrough during the course of the test.

The sulphur loading on this sorbent is 50.69 mgS, or 3.37 mgS/g of sorbent.

5.12.3 Bentonite Mercury Derivative

The bentonite mercury derivative has an experimentally determined BET specific surface area of 20.48 square meters per gram which is considerably less than either of the other two clays tested.

Because of the severe swelling problem experience during the attempted preparation of the bentonite mercury derivative sufficient sample was obtained for a surface area determination but not for inclusion in the flow tests.

5.12.4 Bentonite Nickel Derivative

The bentonite nickel derivative has an experimentally determined BET specific surface area of 23.73 square meters per gram which is considerably less than either of the other two clays tested. The initial column back pressure was 14,500 kPa and decreased to a final value of 7,600 kPa.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.12.3 and Figure 5.12.3. With the exception of thiophenol and thiocresol, all components had essentially complete solute breakthrough at 30 mL throughput volume, 4.9 bed volumes. Thiophenol and thiocresol breakthrough began at 2.5 bed volumes and reached a Ci/Co of 0.90 after 10.7 bed volumes, remaining essentially constant to the end of the test at 25 bed volumes.

The sulphur loading on this sorbent is 12.99 mgS, or 0.87 mgS/g of sorbent.

5.12.5 Bentonite Zinc Derivative

The bentonite zinc derivative has an experimentally determined BET specific surface area of 32.77 square meters per gram which is considerably less than either of the other two clays tested.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.12.4 and Figure 5.12.4. Complete solute breakthrough occurred for 2-thienylbutane, thianaphthene and dibenzothiaphene after 25 mL throughput volume, 3.6 bed volumes. Thiophene, butylsulphide and butyldisulphide had Ci/Co values greater than 0.85 after 5.1 bed volumes and slowly increased to final values of 1.0, 1.0 and 0.90, respectively, during the test. Butanethiol exhibited an initial Ci/Co of about 0.12 which remained essentially constant to 15.2 bed volumes and then increased to 0.95 at the conclusion of the test. Thiophenol and thiocresol breakthrough began at 13.8 bed volumes and increased smoothly to final values of 0.93 and 0.84, respectively, at the conclusion of the test.

The sulphur loading on this sorbent is 44.63 mgS, or 3.17 mgS/g of sorbent.

5.13 Bentonite Chlorhydrol Derivative

The bentonite chlorhydrol derivative has an experimentally determined BET specific surface area of 23.00 square meters per gram which is considerably less than either of the chlorhydrol clay derivatives.

Because of the severe swelling problem experienced during the attempted preparation of the bentonite chlorhydrol derivative, sufficient sample was obtained for a surface area determination but not for inclusion in the flow tests.

5.13.1 Bentonite Chlorhydrol Copper Derivative

The bentonite chlorhydrol copper derivative has an experimentally determined BET specific surface area of 22.77 square meters per gram which is considerably less than either of the chlorhydrol clay derivatives.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.13.1 and Figure 5.13.1. The Ci/Co values for thiophene, 2-thienylbutane, thianaphthene, butyldisulphide and dibenzothiaphene were over 0.75 within 25 mL throughput volume, 4.2 bed volumes, and slowly increased to final values of 1.0, 0.89, 0.91, 0.96 and 0.93, respectively, over the course of the test. Initial breakthrough for butylsulphide occurred at 9.3 bed volumes and slowly increased to 0.62 at the conclusion of the test. Butanethiol reached a maximum of 0.20 and generally stayed around 0.18 during the later stages of the test. Cyclohexanethiol, thiophenol and thiocresol did not breakthrough over the duration of the flow test.

The sulphur loading on this sorbent is 72.10 mgS, or 4.77 mgS/g of sorbent.

5.13.2 Bentonite Chlorhydrol Iron (III) Derivative

The bentonite chlorhydrol iron (III) derivative has an experimentally determined BET specific surface area of 32.73 square meters per gram which is considerably less than either of the chlorhydrol clay derivatives. The initial column back pressure was 12,400 kPa and remained essentially constant over the course of the test.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.13.2 and Figure 5.13.2. Thiophene breakthrough is complete within 20 mL, 3.6 bed volumes, crude oil mixture throughput volume, butylsulphide and thianaphthene within 70 mL, 12.5 bed volumes, dibenzothiaphene within 80 mL, 14.3 bed volumes, and 2-thienylbutane within 90 mL, 16.1 bed volumes. Initial breakthrough for cyclohexanethiol occurred at 9.3 bed volumes and slowly increased to 0.62 at the conclusion of the test. Butanethiol breakthrough occurred early and generally remained around 0.20 until the later stages of the test, reaching a final value of 0.62. Thiophenol and thiocresol breakthrough began at 11.6 bed volumes with Ci/Co values of 0.43 and 0.34, respectively, at the completion of the test.

The sulphur loading on this sorbent is 37.98 mgS, or 2.56 mgS/g of sorbent.

5.13.3 Bentonite Chlorhydrol Mercury Derivative

The bentonite chlorhydrol mercury derivative has an experimentally determined BET specific surface area of 15.85 square meters per gram which is considerably less than other of the clay derivatives.

Because of the severe swelling problem experienced during the attempted preparation of the bentonite chlorhydrol mercury, derivative sufficient sample was obtained for a surface area determination but not for inclusion in the flow tests.

5.13.4 Bentonite Chlorhydrol Nickel Derivative

The bentonite chlorhydrol nickel derivative has an experimentally determined BET specific surface area of 26.62 square meters per gram which is considerably less than any of the chlorhydrol clay derivatives.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.13.4 and Figure 5.13.4. Thiophene has completely broken through after 30 mL throughput volume, 5.0 bed volumes, while all the rest of the components required 7.5 bed volumes for complete breakthrough.

The sulphur loading on this sorbent is 12.62 mgS, or 0.82 mgS/g of sorbent.

5.13.5 Bentonite Chlorhydrol Zinc Derivative

The bentonite chlorhydrol zinc derivative has an experimentally determined BET specific surface area of 35.62 square meters per gram which is considerably less than any of the chlorhydrol clay derivatives.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.13.5 and Figure 5.13.5. The Ci/Co values for thiophene, 2-thienylbutane, thianaphthene, butyldisulphide and dibenzothiaphene were over 0.90 within 20 mL throughput volume, 3.2 bed volumes, and slowly increased to final values of 1.0, 0.94, 0.95, 0.95 and 0.95, respectively, over the course of the test. While progressing somewhat more slowly initially, butanethiol, cyclohexanethiol and butylsulphide reached similar final values. Initial breakthrough for thiophenol and thiocresol occurred at 2.4 bed volumes with final Ci/Co values of 0.86 and 0.83, respectively.

The sulphur loading on this sorbent is 18.75 mgS, or 1.24 mgS/g of sorbent.

5.14 Calcium Montmorillonite

5.14.1 Calcium Montmorillonite Copper Derivative

The calcium montmorillonite copper derivative has an experimentally determined BET specific surface area of 60.36 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.14.1 and Figure 5.14.1. Inspection of the data indicate that cyclohexanethiol, thiophenol and thiocresol did not breakthrough during the test while butanethiol had only minor breakthrough and butylsulphide increased slowly during the test to a final value of 0.64. The remaining components had early breakthrough but then increased slowly during the test.

The sulphur loading on this sorbent is 59.04 mgS, or 3.67 mgS/g of sorbent.

5.14.2 Calcium Montmorillonite Iron (III) Derivative

The calcium montmorillonite iron (III) derivative has an experimentally determined BET specific surface area of 76.25 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.14.2 and Figure 5.14.2. Examination of the data indicates that thiophene had complete solute breakthrough within 35 mL throughput volume, 5.2 bed volumes, however none of the other components reached a Ci/Co of 1.0 in the course of the test. Butanethiol displayed only a small degree of breakthrough the during the course of the flow test while thiophenol and thiocresol did not breakthrough at all while cyclohexanethiol breakthrough began at 14.9 bed volumes and increased to only 0.22 at the conclusion of the test. Butylsulphide, 2-thienylbutane, thianaphthene, butyldisulphide and dibenzothiaphene exhibited a slow increase through the and reached final values of 0.80, 0.77, 0.80, 0.73 and 0.77, respectively.

The sulphur loading on this sorbent is 66.74 mgS, or 4.24 mgS/g of sorbent.

5.14.3 Calcium Montmorillonite Mercury

The calcium montmorillonite mercury derivative has an experimentally determined BET specific surface area of 51.69 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.14.3 and Figure 5.14.3. Examination of the data indicates that butanethiol, cyclohexanethiol, 2-thienylbutane, butylsulphide, thianaphthene, butyldisulphide and dibenzothiaphene have complete solute breakthrough after 25 mL throughput volume, 3.5

bed volumes, while thiophene has reached 0.95 at the same throughput. Thiophenol and thiocresol increase slowly through the test to final values of 1.0 and 0.94, respectively.

The sulphur loading on this sorbent is 22.28 mgS, or 2.15 mgS/g of sorbent.

5.14.4 Calcium Montmorillonite Nickel

The calcium montmorillonite nickel derivative has an experimentally determined BET specific surface area of 70.03 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.14.4 and Figure 5.14.4. Examination of the data indicates that complete solute breakthrough has occurred for thiophene, butanethiol, 2-thienylbutane, thianaphthene and dibenzothiaphene after 25 mL throughput, 3.2 bed volumes. Cyclohexanethiol, thiophenol, thiocresol and butyldisulphide initial breakthrough occurs at 1.9 bed volumes and slowly increases throughout the test. Butylsulphide initial breakthrough is at 3.2 bed volumes and slowly increases.

The sulphur loading on this sorbent is 39.51 mgS, or 3.88 mgS/g of sorbent.

5.14.5 Calcium Montmorillonite Zinc

The calcium montmorillonite zinc derivative has an experimentally determined BET specific surface area of 70.69 square meters per gram. The initial column back pressure was 2,400 kPa and remained constant throughout the test

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.14.5 and Figure 5.14.5. Examination of the data indicates that thiophene, 2-thienylbutane, butylsulphide, thianaphthene, butyldisulphide and dibenzothiaphene have complete solute breakthrough after 30 mL throughput volume, 5.3 bed volumes. The remaining components increase slowly through the test to complete breakthrough within 14.0 bed volumes.

The sulphur loading on this sorbent is 16.93 mgS, or 1.07 mgS/g of sorbent.

5.15.1 Calcium Montmorillonite Chlorhydrol Derivative

The calcium montmorillonite chlorhydrol derivative has an experimentally determined BET specific surface area of 65.22 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.15.1 and Figure 5.15.1. Complete solute breakthrough for thiophene and butanethiol was attained after 30 mL throughput volume, 3.8 bed volumes. The Ci/Co values for cyclohexanethiol, 2-thienylbutane, butylsulphide, thianaphthene, butyldisulphide and dibenzothiaphene reached 0.90 at 3.8 bed volumes and remained essentially stable for the remainder of the test. Breakthrough for thiophenol and thiocresol began at 1.9 bed volumes and slowly increased to final values of 0.74 and 0.70, respectively, over the course of the test.

The sulphur loading on this sorbent is 27.88 mgS, or 2.76 mgS/g of sorbent.

5.15.2 Calcium Montmorillonite Chlorhydrol Copper Derivative

The calcium montmorillonite chlorhydrol copper derivative has an experimentally determined BET specific surface area of 67.85 square meters per gram. The initial column back pressure was 11,700 kPa and remained stable throughout the test.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.15.2 and Figure 5.15.2. Complete solute breakthrough for thiophene was attained after 35 mL throughput volume, 4.9 bed volumes. The Ci/Co values for 2-thienylbutane, thianaphthene and dibenzothiaphene reached 0.90 at 4.2 bed volumes and remained essentially stable for the remainder of the test. Butanethiol reached a maximum of 0.30 at the conclusion of the test. Butyldisulphide breakthrough began at 2.1 bed volumes, increase rapidly to 0.70 at 4.2 bed volumes and then slowly increased to a final value of 0.90. Butylsulphide breakthrough began at 8.33 bed volumes and increased slowly to a final value of 0.69. Cyclohexanethiol, thiophenol and thiocresol did not breakthrough during the test.

The sulphur loading on this sorbent is 81.87 mgS, or 6.54 mgS/g of sorbent.

5.15.3 Calcium Montmorillonite Chlorhydrol Iron (III) Derivative

The calcium montmorillonite chlorhydrol iron (III) derivative has an experimentally determined BET specific surface area of 64.43 square meters per gram. The initial column back pressure was 8,300 kPa and remained stable throughout the test.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.15.3 and Figure 5.15.3. Complete solute breakthrough for butylsulphide and dibenzothiaphene occurred at 5.0 bed volumes, for butyldisulphide at 5.7 bed volumes with thiophene and thianaphthene being essentially complete at 5.0 bed volumes.

Butanethiol breakthrough was complete at 17.1 bed volumes. Breakthrough began at 7.8 bed volumes for cyclohexanethiol and thiophenol and 10.0 bed volumes for thiocresol. These components reached final Ci/Co values of 0.60, 0.42 and 0.30, respectively.

The sulphur loading on this sorbent is 64.12 mgS, or 5.47 mgS/g of sorbent.

5.15.4 Calcium Montmorillonite Chlorhydrol Mercury Derivative

The calcium montmorillonite chlorhydrol mercury derivative has an experimentally determined BET specific surface area of 68.41 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.15.4 and Figure 5.15.4. Complete solute breakthrough for 2-thienylbutane, butylsulphide, thianaphthene, butyldisulphide and dibenzothiaphene occurred at 4.6 bed volumes and for cyclohexanethiol at 7.4 bed volumes. Ci/Co increased slowly throughout the test for thiophene, butanethiol, thiophenol and thiocresol reaching final values of 0.89, 0.89, 0.91 and 0.86, respectively.

The sulphur loading on this sorbent is 19.09 mgS, or 1.24 mgS/g of sorbent.

5.15.5 Calcium Montmorillonite Chlorhydrol Nickel Derivative

The calcium montmorillonite chlorhydrol nickel derivative has an experimentally determined BET specific surface area of 42.69 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.15.5 and Figure 5.15.5. Complete solute breakthrough for butanethiol occurred at 3.3 bed volumes, for thianaphthene at 3.9 bed volumes, for butylsulphide and dibenzothiaphene at 4.6 bed volumes, 2-thienylbutane at 7.9 bedvolumes and thiophene at 11.2 bed volumes. Initial breakthrough for cyclohexanethiol, thiophenol and thiocresol began early in the test and increased slowly to final values of 0.84, 0.88 and 0.85, respectively.

The sulphur loading on this sorbent is 19.83 mgS, or 1.62 mgS/g of sorbent.

5.15.6 Calcium Montmorillonite Chlorhydrol Zinc Derivative

The calcium montmorillonite chlorhydrol zinc derivative has an experimentally determined BET specific surface area of 59.24 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.15.6 and Figure 5.15.6. Complete solute breakthrough for 2-thienylbutane, butylsulphide, thianaphthene, butyldisulphide and dibenzothiaphene occurred 3.9 bed volumes, and for cyclohexanethiol at 6.2 bed volumes. Initial breakthrough for thiophene, butanethiol, thiophenol and thiocresol began early in the test and increased slowly to final values of 0.89, 0.89, 0.91 and 0.86, respectively.

The sulphur loading on this sorbent is 20.51 mgS, or 1.32 mgS/g of sorbent.

5.16 Zeolite X-13

Zeolite X-13 derivatives with calcium, copper, hydrogen, mercury and zinc were prepared as previously described. These derivatives were dried at 300 C and 500 C prior to testing.

5.16.1 Zeolite X-13 Calcium @ 300 C

The zeolite X-13 calcium derivative dried at 300 C has an experimentally determined BET specific surface area of 356.13 square meters per gram. The initial column back pressure was 5,500 kPa and remained essentially constant throughout the test.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.16.1 and Figure 5.16.1. Complete solute breakthrough is attained within 5.4 bed volumes for all components.

The sulphur loading on this sorbent is 10.25 mgS, or 1.19 mgS/g of sorbent.

5.16.2 Zeolite X-13 Copper @ 300 C

The zeolite X-13 copper derivative dried at 300 C has an experimentally determined BET specific surface area of 15.92 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.16.2 and Figure 5.16.2. Complete solute breakthrough is attained within 2.7 bed volumes for butyldisulphide and 4.8 bed volumes for thiophene. Butylsulphide, 2-thienylbutane, thianaphthene and dibenzothiaphene reach a Ci/Co greater than 0.90 after 3.4 bed volumes and slowly increase through the remainder of the test. Butanethiol remains essentially constant at 0.26 throughout the test while cyclohexanethiol, thiophenol and thiocresol do not breakthrough at all during the course of the test.

The sulphur loading on this sorbent is 69.26 mgS, or 7.28 mgS/g of sorbent.

5.16.3 Zeolite X-13 Hydrogen @ 300 C

The zeolite X-13 hydrogen derivative dried at 300 C has an experimentally determined BET specific surface area of 52.91 square meters per gram. The initial column back pressure was 5,400 kPa and remained essentially constant throughout the test.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.16.3 and Figure 5.16.3. With the exception of thiophene, which had complete breakthrough at 6.4 bed volumes, all components have complete solute breakthrough within 3.8 bed volumes.

The sulphur loading on this sorbent is 11.16 mgS, or 1.92 mgS/g of sorbent.

5.16.4 Zeolite X-13 Mercury @ 300 C

The zeolite X-13 mercury derivative dried at 300 C has an experimentally determined BET specific surface area of 11.19 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.16.4 and Figure 5.16.4. Examination of the data indicates that all components have complete solute breakthrough within 4.5 bed volumes.

The sulphur loading on this sorbent is 10.30 mgS, or 1.20 mgS/g of sorbent.

5.16.5 Zeolite X-13 Zinc @ 300 C

The zeolite X-13 zinc derivative dried at 300 C has an experimentally determined BET specific surface area of 173.72 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.16.5 and Figure 5.16.5. Examination of the data indicates that all components have complete solute breakthrough at 4.3 bed volumes.

The sulphur loading on this sorbent is 11.00 mgS, or 1.25 mgS/g of sorbent.

5.16.6 Zeolite X-13 Calcium @ 500 C

The zeolite X-13 calcium derivative dried at 500 C has an experimentally determined BET specific surface area after heating to 400 C of 349.55 square meters per gram, which is comparable to the 300 C sample. The initial column back pressure was 6,200 kPa and remained essentially constant throughout the test.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.16.6 and Figure 5.16.6. Complete solute breakthrough is attained within 4.4 bed volumes for all components.

The sulphur loading on this sorbent is 9.65 mgS, or 1.16 mgS/g of sorbent.

5.16.7 Zeolite X-13 Copper @ 500 C

The zeolite X-13 calcium derivative dried at 500 C has an experimentally determined BET specific surface area after heating to 400 C of 16.27 square meters per gram, which is slightly greater than the 300 C sample.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.16.7 and Figure 5.16.7. Complete solute breakthrough is attained for 2-thienylbutane, butylsulphide, thianaphthene, butyldisulphide and dibenzothiaphene within 4.2 bed volumes and for cyclohexanethiol at 6.9 bed volumes. Thiophene and butanethiol reach 0.90 at 4.2 bed volumes and remain essentially constant throughout the test. Thiophenol and thiocresol reach 0.80 at 4.2 bed volumes and slowly increase to final values of 0.94 and 0.91, respectively.

The sulphur loading on this sorbent is 17.61 mgS, or 1.93 mgS/g of sorbent.

5.16.8 Zeolite X-13 Hydrogen @ 500 C

The zeolite X-13 hydrogen derivative dried at 500 C has an experimentally determined BET specific surface area after heating to 400 C of 56.55 square meters per gram which is slightly greater than the 300 C sample.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.16.8 and Figure 5.16.8. With the exception of thiophene, which had complete breakthrough at 5.4 bed volumes, all components have complete solute breakthrough within 3.4 bed volumes.

The sulphur loading on this sorbent is 15.14 mgS, or 2.65 mgS/g of sorbent.

5.16.9 Zeolite X-13 Mercury @ 500 C

The zeolite X-13 mercury derivative dried at 500 C has an experimentally determined BET specific surface area after heating to 400 C of 10.60 square meters per gram which is slightly less than that of the 300 C sample.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.16.9 and Figure 5.16.9. Examination of the data indicates that all components have complete solute breakthrough within 3.6 bed volumes.

The sulphur loading on this sorbent is 10.31 mgS, or 1.27 mgS/g of sorbent.

5.16.10 Zeolite X-13 Zinc @ 500 C

The zeolite X-13 zinc derivative dried at 500 C has an experimentally determined BET specific surface area after heating to 400 C of 313.05 square meters per gram which is nearly twice as great as that of the 300 C sample.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.16.10 and Figure 5.16.10. Examination of the data indicates that, with the exception of thiophene and butanethiol, all components have complete solute breakthrough at 3.4 bed volumes. Thiophene and thiocresol increase rapidly to approximately 0.90 at 3.4 bed volumes and more slowly to final values of 1.0 at 11.6 bed volumes.

The sulphur loading on this sorbent is 11.15 mgS, or 1.34 mgS/g of sorbent.

5.17.1 Activated Charcoal 6-15 Mesh

Activated charcoal 6-15 mesh has an experimentally determined BET specific surface area of 780.21 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.17.1 and Figure 5.17.1. Examination of the data indicates that complete solute breakthrough for butyldisulphide occurred at 3.5 bed volumes, for thiophene, 2-thienylbutane, butylsulphide and thianaphthene at 7.0 bed volumes. Butanethiol and cyclohexanethiol increase slowly throughout the test to final values of 0.86 and 0.94, respectively. Thiophene and thiocresol remain at approximately 0.05 throughout the test. Initial breakthrough for dibenzothiaphene occurs at 5.6 bed volumes and increases slowly throughout the test to a final value of 0.82.

The sulphur loading on this sorbent is 50.72 mgS, or 8.54 mgS/g of sorbent.

5.17.2 Activated Charcoal 50-200 Mesh

Activated charcoal 50-200 mesh has an experimentally determined BET specific surface area of 1334.82 square meters per gram.

The Ci/Co versus synthetic crude oil throughput volume data are presented in Table 5.17.2 and Figure 5.17.2. Examination of the data indicates that complete solute breakthrough for butyldisulphide occurred at 3.5 bed volumes, for thiophene, 2-thienylbutane, butylsulphide and thianaphthene at 7.0 bed volumes. Butanethiol and cyclohexanethiol increase slowly throughout the test to final values of 0.86 and 0.94, respectively. Thiophene and thiocresol remain at approximately 0.05 throughout the test. Initial breakthrough for dibenzothiaphene occurs at 5.6 bed volumes and increases slowly throughout the test to a final value of 0.82.

The sulphur loading on this sorbent is 56.22 mgS, or 12.78 mgS/g of sorbent.

6.0 SUMMARY OF RESULTS

The nature of exchanged cations in zeolites is known to affect adsorption capacities and hence porosities and surface areas as a function of competition between surface electrical charge density and the sieve effect (10).

Clays are known to adsorb a wide variety of polar organic constituents of crude oil contained in both pentane soluble and insoluble fractions (11, 12). Adsorption is influenced both by the exchangeable cation and the dielectric constant of the solvent used (13).

The behavior of ion exchange resins with nonaqueous solvents has been related to chemical composition of the resin polymers, the degree of cross linking and the porosity (14). In general, swelling and hence porosity is greater for polar solvents. Ion exchange capacities and kinetics decline with decreasing polarity of the solvent, which would be the case with toluene as the solvent. The screening, or sieve, effect may influence exchange with higher molecular weight compounds in the model solution.

In a previous study (6) the selective removal of nitrogenous compounds from fuels by adsorption onto zeolites was investigated. A wide range of nitrogenous compounds were employed and the extent of the sorption of these materials was found to be greatly varied and sensitive to the nature of the zeolite used and the chemical and physical nature of the solute. In the current study, ten sulphurous compounds, which are analogous to some of the previously tested nitrogenous compounds, were tested for sorption onto ion exchange resins, zeolites, clays, pillared clays and activated carbon.

In comparison to the previous study, the sorption behavior of the sulphurous compounds tested here fall generally into to classes; those compounds which have an acidic sulphur group, ie butanethiol, cyclohexanethiol, thiophenol and thiocresol, displayed the greatest loading while those compounds which did not have an acidic sulphur group; ie thiophene, 2-thienylbutane, butylsulphide, thianaphthene, butyldisulphide and dibenzothiaphene, displayed the least loading.

With the exception of IRN-78, which is an anionic exchange resin, the underivatized resins, IRN-77, IR-124, IR-130C, XAD-2, XAD-7 and XAD-8 are cationic exchange resins. In testing these resins, the IRN-78 resin was most effective in removing test compounds from the synthetic crude oil mixture, and only then those components which have ionizable sulphur groups.

Amberlyst XN-1010, which is a cationic exchange resin, was exchanged with a variety of metal cations prior to testing. In general, the best sulphur loading was obtained with those metals which can form stable sulphides; copper, iron, mercury, and to a lesser degree titanium and zinc. However, as can be seen by inspection of the experimental results, the sorption was quite selective to those compounds which have acidic sulphurs, as noted above. Since this is a cation exchange resin, actual exchange is not responsible for the loading, hence there must be chemical interaction between the metal cation and the solute.

Amberlyst 15, which is also a cationic exchange resin, was exchanged with the same metal cations as XN-1010 prior to testing. Again, the best sulphur loading was obtained with those metals which can form stable sulphides; copper, iron, mercury and to a lesser degree titanium and zinc. As with the previous case, the sorption was quite selective to those compounds which have acidic sulphurs, as noted above. Again, since this is a cationic exchange resin, actual exchange is not responsible for the loading, hence there must be chemical interaction between the metal cation and the solute.

In the case of the clays, the metals used in preparation of the derivatives can all form stable sulphides and hence the sulphur loading on the clays was generally greater than that of the resins. It should be noted that although mercury derivatives of the clays do exhibit sulphur loading, the mercury content of the clays is very low as compared to the other metal contents of the other derivatives.

There did not appear to be any physical change in the appearance of the clays during preparation of the pillared clays. The pillared clay preparation was repeated twice with the same result. A comparison of the surface areas of the pillared and unpillared clays, Table 4.1, indicates that there is little difference in the surface areas of the pillared and unpillared clays. The experiments of Occelli and Tindwa (8) utilized sodium montmorillonite, which had been previously studied and was known to undergo reaction with chlorhydrol. The crystalline structure of sodium montmorillonite can have 1, 2, 3 or more layers per unit cell, with inter-layer spacings of 12.5, 15.5 or 19 angstroms, respectively. This is in comparison to calcium montmorillonite, studied here, which has two layers per unit cell with spacing of 15.5 angstroms. The inter-layer spacing of these clays varies from 10 to 21 angstroms depending upon the cation and the extent of hydration. Hence the variations in the crystal lattice, as noted, between the sodium form, as studied by Occelli and Tindwa, and the calcium form studied here, may be sufficient to preclude interaction with the chlorhydrol molecule which must enter the inter-layer void to effect swelling. Conversely, the inter-layer spacing of the calcium form may be large enough to allow the chlorhydrol to enter without dramatically affecting the inter-layer spacing. An additional consideration is that the clays were cation exchanged with the various metals prior to chlorhydrol treatment. The introduction of the metals into the inter-layers may have reduced the inter-layer spacing an extent that the reaction with chlorhydrol could not proceed.

Attapulgite and the pillared attapulgite derivatives all displayed sulphur loading with the exception of the pillared nickel derivative which was least effective. The attapulgite copper and mercury derivatives have the greatest loading while in the pillared case it was copper and iron. It should be noted that for the pillared clay, the mercury derivative had no detectable mercury whereas the unpillared clay contained 0.3 wt% mercury. Hence the lack of loading in the pillared mercury derivative would seen to be due the lack of mercury. As noted above, the sulphur removal was most selective to those components having acidic sulphur groups.

The bentonite and pillared bentonite chlorhydrol derivatives all displayed sulphur loading, again the pillared nickel derivative was the least effective. As noted earlier, the mercury derivatives were not flow tested because of severe swelling which occurred during their preparation. As in the attapulgite case, the copper derivative display the greatest loading while iron is second. As noted above, the sulphur removal was most selective to those components having acidic sulphur groups.

The calcium montmorillonite and pillared calcium montmorillonite chlorhydrol derivatives all display sulphur loading, including the mercury derivative although, as can be seen in Table 4.2, these derivatives contained no detectable mercury. As in the previous examples, the copper and iron derivatives were most effective and sulphur removal was most selective to those components having acidic sulphur groups.

In the case of zeolite X-13, preconditioned at 300 C and 500 C, only the copper derivatives were effective in removing sulphur. These results are surprising in view of the previous study (6) involving zeolites and nitrogenous compounds which found significant nitrogen loading for a variety of compounds. However, the previous study did not involve cation exchanged zeolites, which may have led to the lack of sulphur loading in this test. The method employed here to prepare the cation exchanged zeolites, flowing the cation solutions over the zeolites contained in a glass column, may not have resulted in the exchange being uniform throughout. Since cation exchange on zeolites is a slow process, the zeolites at the top of the column may have been more completely exchanged than the material at the bottom of the column. A more appropriate procedure for obtaining a uniform cation exchange would be to prepare a slurry of the zeolites in the cation containing solution at a temperature of 60-90 C.

The ten most effective sorbents are:

Attapulgite Copper	14.43 mgS/g of sorbent
Activated Carbon 50-200 Mesh	12.78 mgS/g of sorbent
Attapulgite Chlorhydrol Copper	11.11 mgS/g of sorbent
Activated Carbon 6-15 Mesh	8.54 mgS/g of sorbent
Zeolite X-13 Copper @ 300 C	7.28 mgS/g of sorbent
Amberlyst 15 Copper	7.09 mgS/g of sorbent
Amberlyst XN-1010 Copper	6.92 mgS/g of sorbent

Calcium Montmorillonite Chlorhydrol Copper	6.54 mgS/g of sorbent
Amberlyst XN-1010 Iron	6.42 mgS/g of sorbent
Amberlite IRN-78	6.16 mgS/g of sorbent

7.0 RECOMMENDATIONS

There are several aspects of this study which could benifit from additional research:

1. Preparation of the pillared clays with the normal and cation exchanged underivatized clays did not appear to be successAwith the exception of bentonite which displayed tremendous swelling upon contact with chlorhydrol. It is possible that the cation exchange process altered the inter-layer spacing of the clays to the extent that reaction with chlorhydrol was impossible. Examination of the pillaring procedure, and its application to cation exchanged clays, would be useful.

2. The preparation of the metal cation exchanged zeolites involved flowing the cation solutions over the zeolite in a glass column. It ensure a more uniform cation exchange it may be more appropriate to carry out the exchange in slurry at slightly a elevated temperature. These tests should be repeated with zeolites so prepared.

3. While some of the sorbents tested here appear to be quite effective in removing sulphurous compounds which have ionizable sulphurs, the cost of the sorbents in addition to environmental concerns, would preclude simply using and discarding the exhausted sorbents. A study should be undertaken to investigate the potential for recycling the sorbents.

4. The affect of temperature on the sorbent efficiency should be evaluated.

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TABLE 5.1 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlite IRN-77

Sorbent Weight: 9.69 g Column Bed Volume: 5.5 mL Flowrate: 0.46 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5		0	0	0.02	0	0	0.01	0	0.12	0.1
10		0.12	0.14	0.11	0.15	0.10	0.15	0.14	0.15	0.15
15		0.77	0.69	0.56	0.68	0.55	0.67	0.63	0.65	0.67
20		0.91	0.87	0.73	0.90	0.75	0.90	0.91	0.96	0.99
25		0.92	0.87	0.77	0.86	0.78	0.86	1.0	1.0	1.0
30		1.0	1.0	1.0	1.0	1.0	1.0			

COMMENTS:

The thiophene chromatographic peak is strongly overlapped by methanol.

FIGURE 5.1: Ci/Co FOR AMBERLITE IRN-77

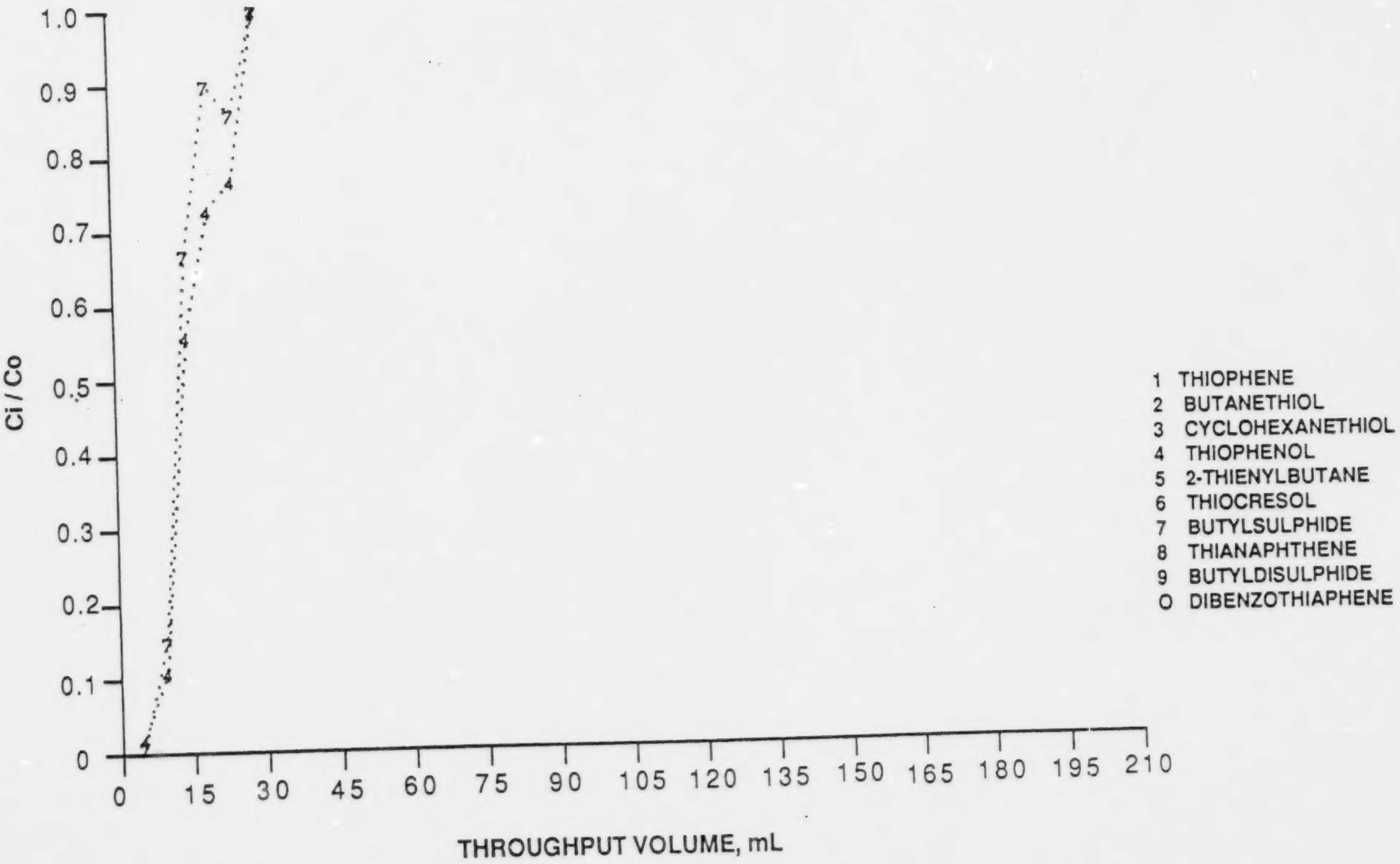

TABLE 5.2 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlite IRN-78

Sorbent Weight: 7.95 g Column Bed Volume: 5.4 mL Flowrate: 0.42 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.74	0	0	0	0	0	0	0	0	0
10	0.70	0	0	0	0.03	0	0.11	0.05	0.07	0.16
15	0.52	0	0	0	0.43	0	0.49	0.40	0.55	0.55
20	0.57	0	0	0	0.67	0	0.74	0.67	0.83	0.82
25	0.49	0	0	0	0.68	0	0.75	0.69	0.84	0.81
30	0.55	0	0	0	0.80	0	0.87	0.81	0.97	0.97
35	0.60	0	0	0	0.88	0	0.93	0.96	0.98	0.98
40	0.67	0	0.07	0	0.95	0	1	1	1	1
45	0.75	0	0.10	0	0.96	0				
50	0.85	0	0.19	0	0.98	0				
55	0.98	0	0.42	0	1	0				
60	1	0	0.52	0		0				
65		0	0.71	0		0				
70		0	0.47	0		0				
75		0	0.52	0		0				
80		0	0.47	0		0				
85		0	0.76	0		0				
90		0	1	0		0				

COMMENTS:

Butanethiol, thiophenol, and thiocresol did not break through during the 25 BV duration of the test. The thiophene chromatographic peak is strongly overlapped by methanol.

FIGURE 5.2: Ci/Co FOR AMBERLITE IRN-78

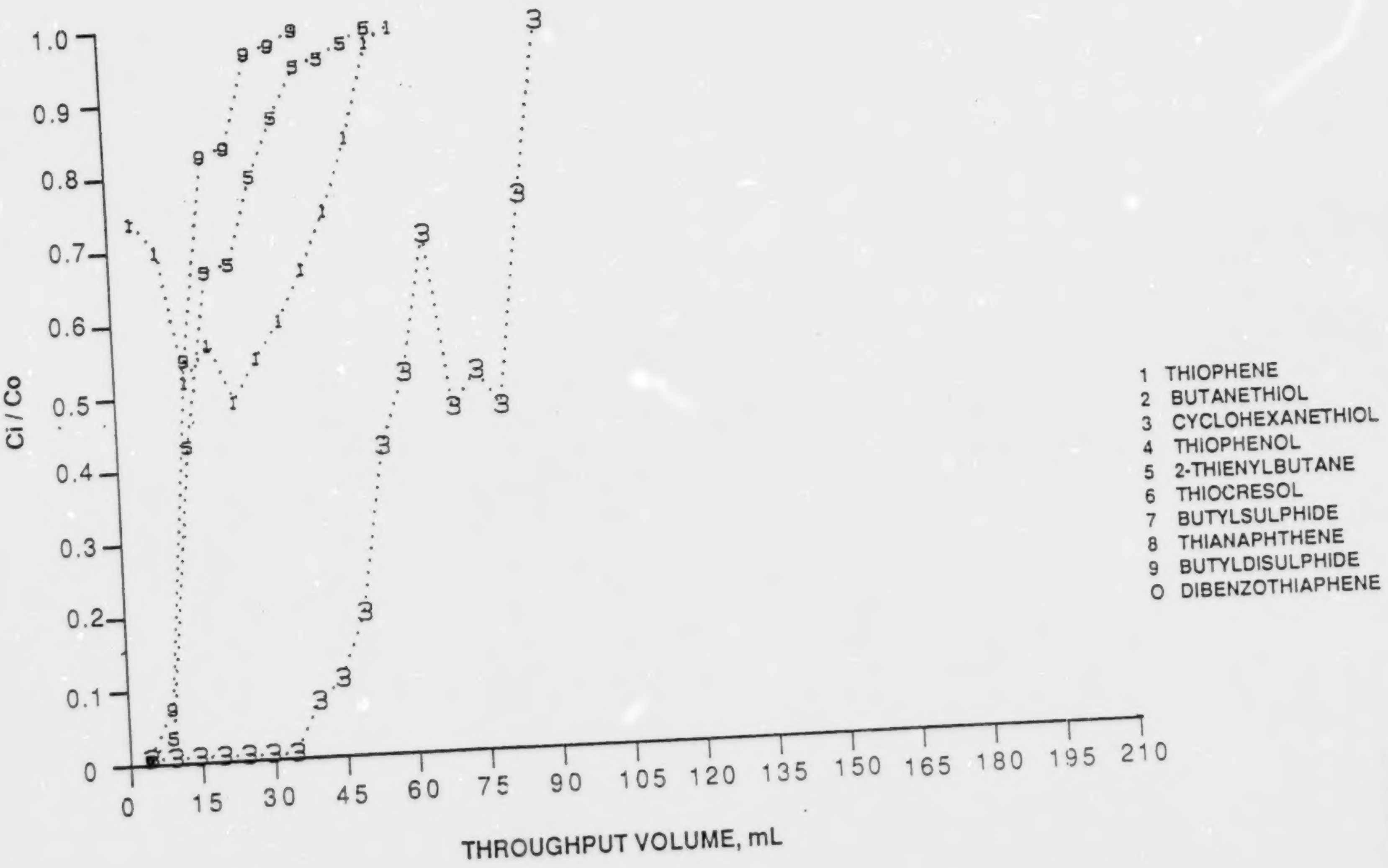

TABLE 5.3 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlite IR-124

Sorbent Weight: 10.35 g Column Bed Volume: 4.9 mL Flowrate: 0.42 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5		0	0	0	0	0	0	0	0	0
10		0.06	0.08	0.08	0.09	0.07	0.09	0.08	0.08	0.09
15		0.74	0.75	0.70	0.74	0.70	0.74	0.72	0.71	0.72
20		0.87	0.89	0.86	0.89	0.86	0.90	0.89	0.86	0.90
25		0.94	0.99	0.96	0.98	0.95	0.97	0.96	0.94	0.92
30		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

COMMENTS:

The thiophene chromatographic peak is strongly overlapped by methanol.

FIGURE 5.3: Ci/Co FOR AMBERLITE IR-124

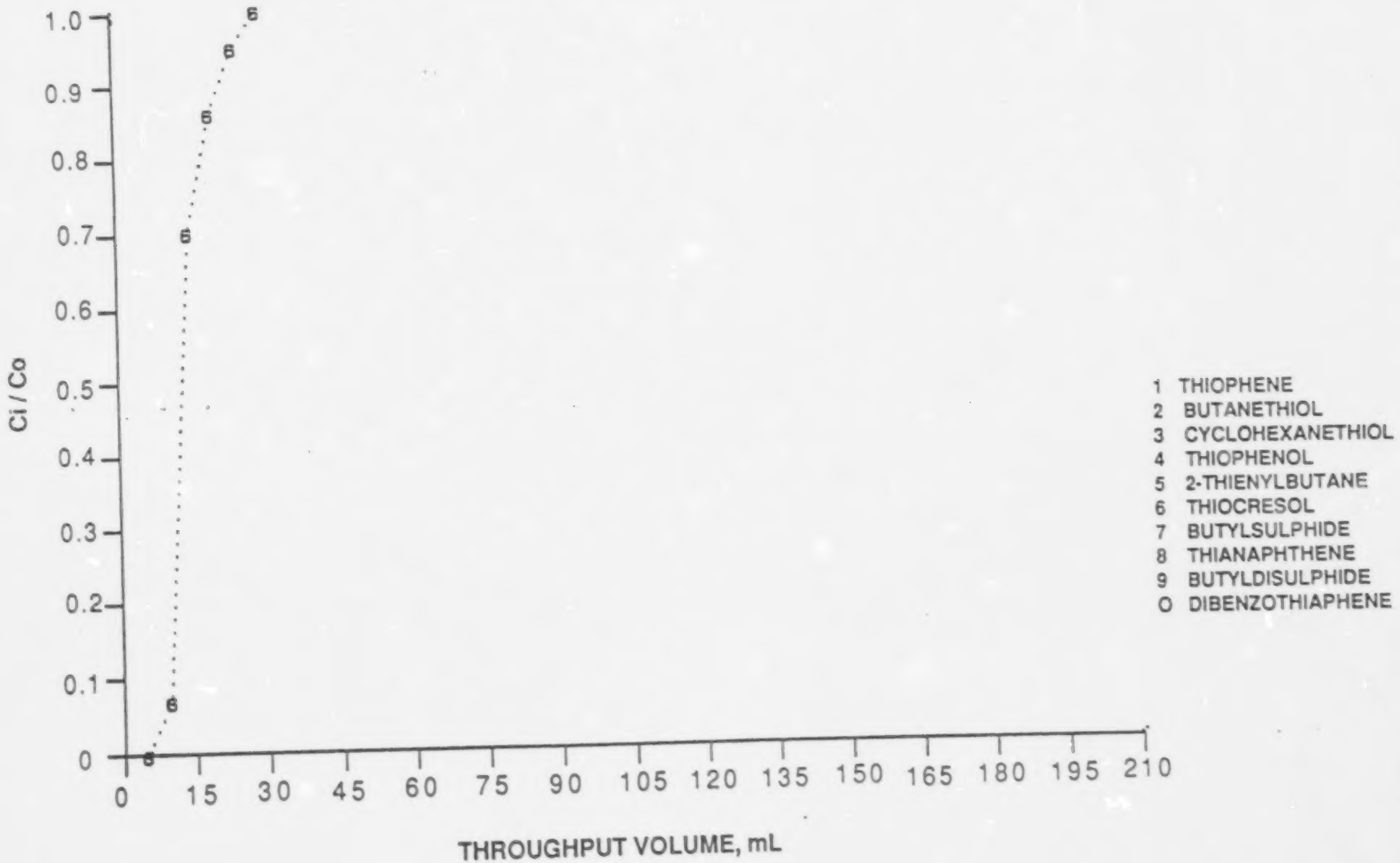

TABLE 5.4 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlite IR-130C

Sorbent Weight: 9.91 g Column Bed Volume: 6.2 mL Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5		0.06	0	0.03	0	0	0	0	0	0
10		0.18	0.28	0.23	0.31	0.23	0.31	0.30	0.31	0.30
15		0.88	0.96	0.91	0.98	0.93	0.99	0.96	0.98	0.96
20		0.91	0.99	0.96	1.0	0.97	1.0	1.0	1.0	1.0
25		0.98	1.0	1.0						
30		1.0								

COMMENTS:

The thiophene chromatographic peak is strongly overlapped by methanol.

FIGURE 5. 4: Ci/Co FOR AMBERLITE IR-130C

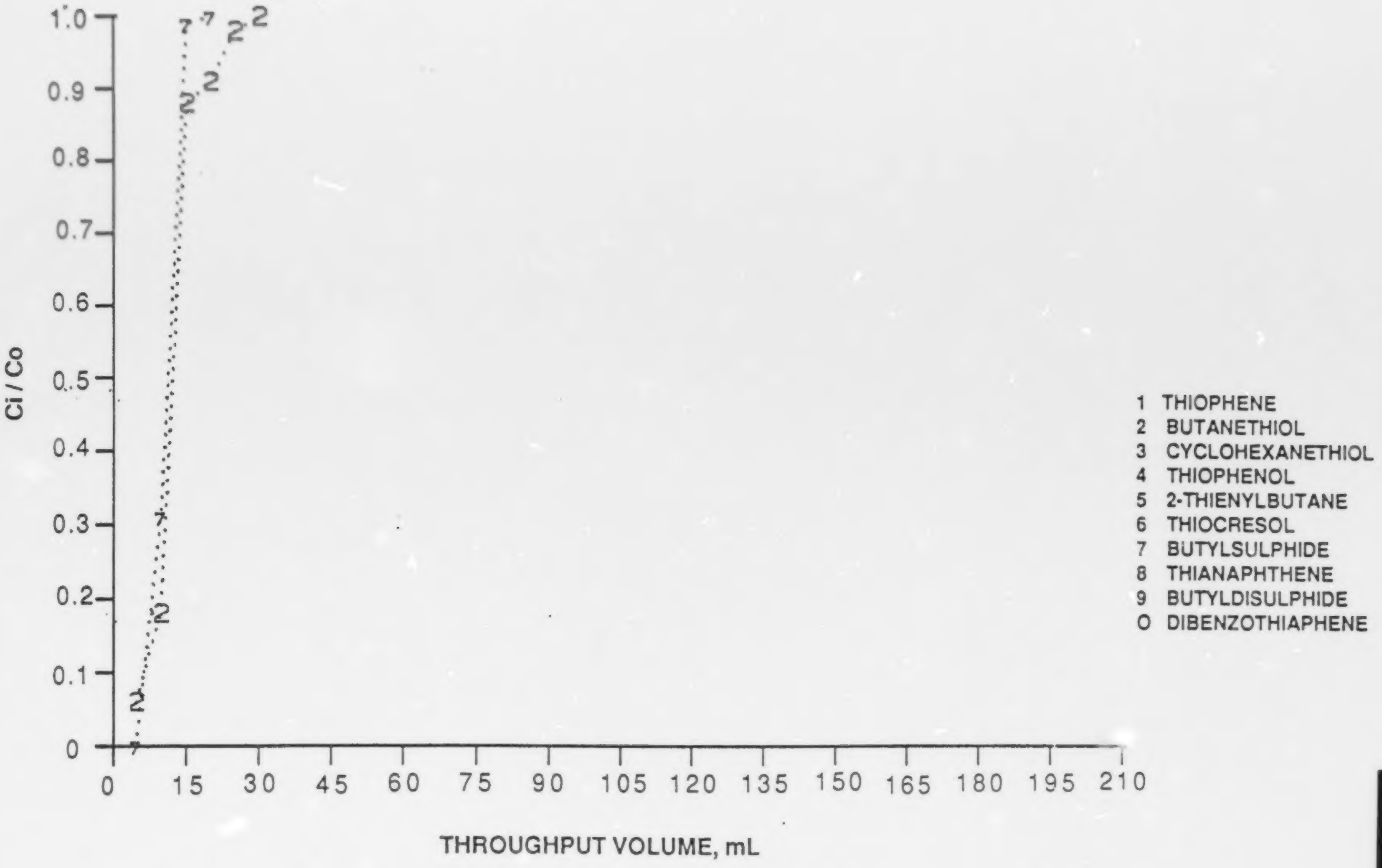

TABLE 5.5 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlite XAD-2

Sorbent Weight: 4.73 g Column Bed Volume: 8.1 mL Flowrate: 0.67 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5			0	0	0	0	0	0	0	0
10			0	0	0	0	0	0	0	0
15			0.40	0.28	0.44	0.32	0.45	0.37	0.44	0.36
20			0.72	0.68	0.72	0.56	0.68	0.70	0.75	0.74
25			0.88	0.87	0.88	0.87	0.88	0.88	0.89	0.86
30			0.90	0.90	0.90	0.89	0.89	0.90	0.91	0.94
35			1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

COMMENTS:

The thiophene chromatographic peak is strongly overlapped by methanol. The butanethiol peak was interferred with by a broad peak of unkown origin.

FIGURE 5.5: AMBERLITE XAD-2

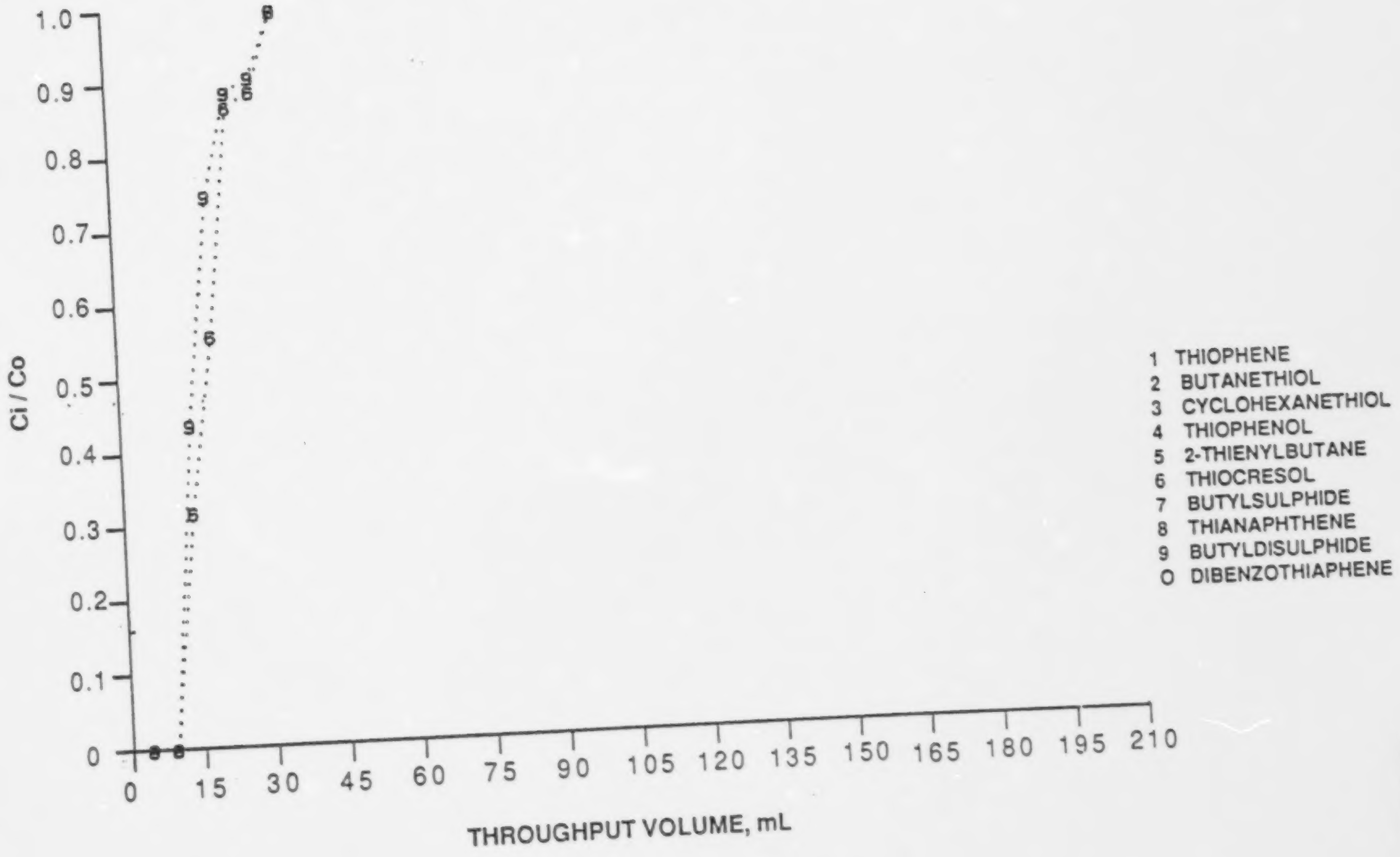

TABLE 5.6 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlite XAD-7

Sorbent Weight: 4.14 g Column Bed Volume: 8.6 mL Flowrate: 0.67 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5			0	0	0	0	0	0	0	0
10			0	0.01	0.01	0	0.01	0	0.01	0
15			0.14	0.08	0.16	0.08	0.16	0.10	0.17	0.11
20			0.61	0.47	0.59	0.47	0.60	0.48	0.67	0.47
25			0.87	0.77	0.78	0.72	0.76	0.71	0.61	0.67
30			1.0	0.95	0.91	0.91	0.89	9.89	0.89	0.87
35				1.0	0.99	0.98	0.98	0.99	1.0	1.0
40					1.0	1.0	1.0	1.0		

COMMENTS:

The thiophene chromatographic peak is strongly overlapped by methanol. The butanethiol peak was interferred with by a broad peak of unkown origin.

FIGURE 5.6: Ci/Co FOR AMBERLITE XAD-7

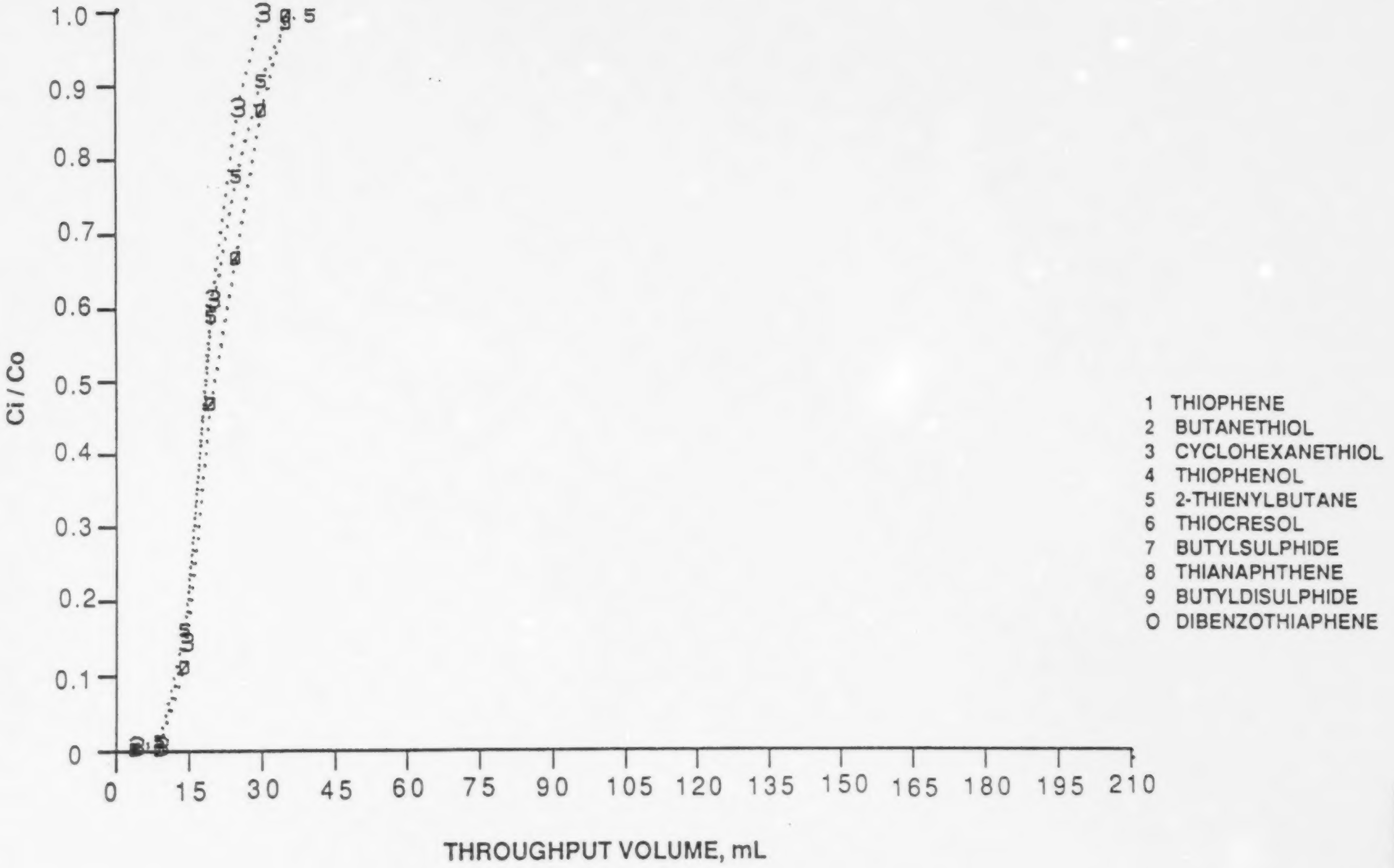

TABLE 5.7 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlite XAD-8

Sorbent Weight: 4.49 g Column Bed Volume: 8.2 mL Flowrate: 0.75 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5		0	0	0.01	0	0	0.05	0	0	0.01
10		0.13	0.19	0.09	0.22	0.1	0.26	0.12	0.28	0.13
15		0.77	0.72	0.56	0.74	0.62	0.77	0.62	0.76	0.61
20		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

COMMENTS:

The thiophene chromatographic peak is strongly overlapped by methanol.

FIGURE 5.7: Ci/Co FOR AMBERLITE XAD-8

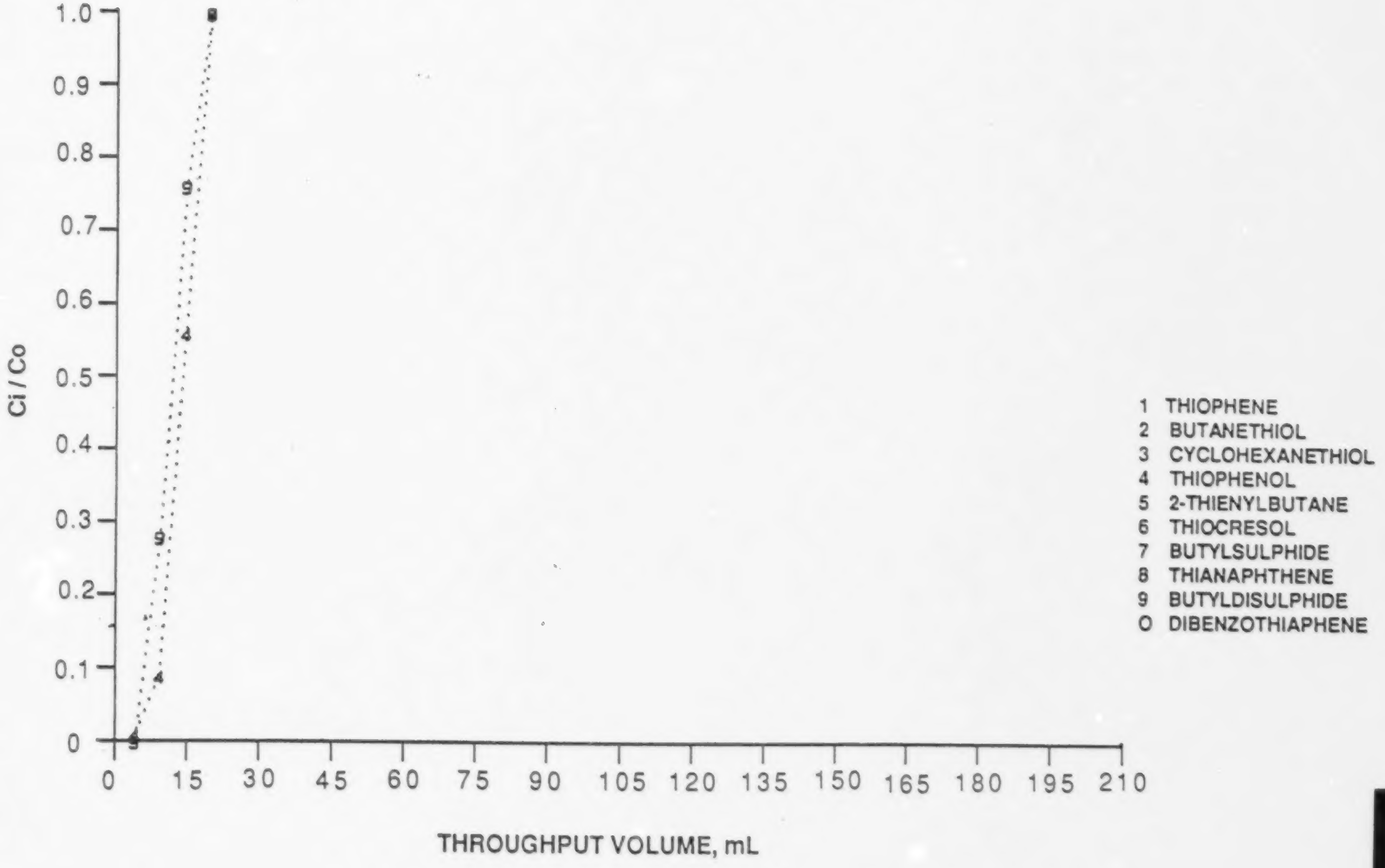

TABLE 5.8.1 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlyst XN-1010 Barium

Sorbent Weight: 8.22 g Column Bed Volume: 6.2 mL Flowrate: 0.5 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5		0	0	0	0.12	0	0	0	0	0
10		0	0	0	0	0	0	0	0	0
15		0.20	0.41	0.19	0.55	0.18	0.58	0.50	0.56	0.51
20		0.65	0.87	0.69	1.0	0.66	1.0	1.0	1.0	1.0
25		0.71	0.84	0.74		0.72				
30		0.83	0.90	0.84		0.83				
35		0.87	0.94	0.89		0.89				
40		0.9	0.99	0.94		0.94				
45		0.99	1.0	1.0		1.0				
50		1.0								

COMMENTS:

The thiophene chromatographic peak is strongly overlapped by methanol.

FIGURE 5.8.1: Ci/Co FOR AMBERLYST XN-1010 BARIUM

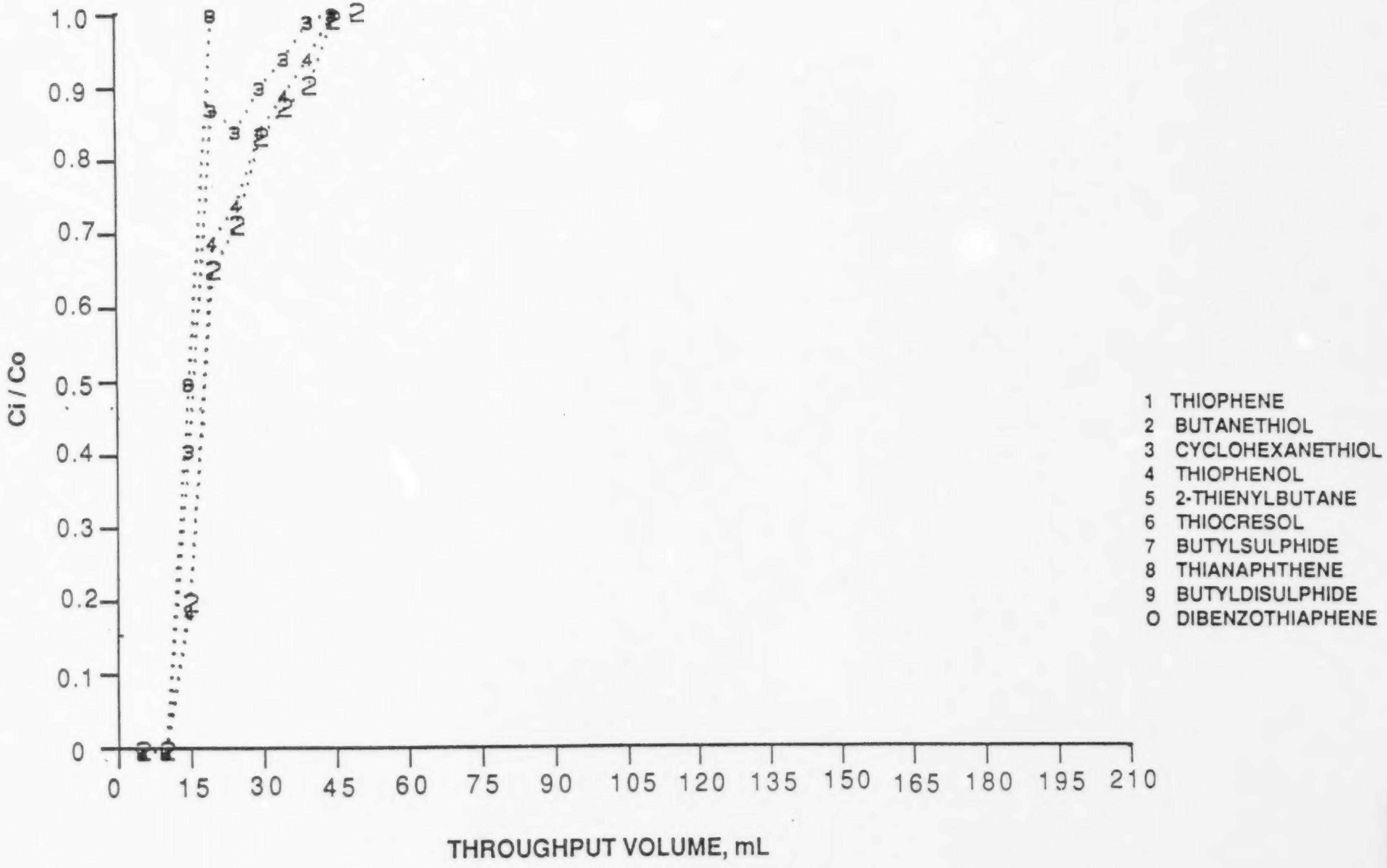

TABLE 5.8.2 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlyst XN-1010 Copper

Sorbent Weight: 7.90 g Column Bed Volume: 6.3 mL Flowrate: 0.5 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5		0	0	0	0	0	0	0.13	0	0.05
10		0	0	0	0.59	0	0.59	0.51	0.66	0.48
15		0	0	0	0.96	0	0.91	0.85	1.0	1.0
20		0	0	0	1.0	0	1.0	1.0		

COMMENTS:

The thiophene chromatographic peak is strongly overlapped by methanol.
Components butanethiol, cyclohexanethiol, thiophenol, and thiocresol did not break through during the 25 BV duration of the test.

FIGURE 5.8.2:   Ci/Co FOR AMBERLYST XN-1010 COPPER

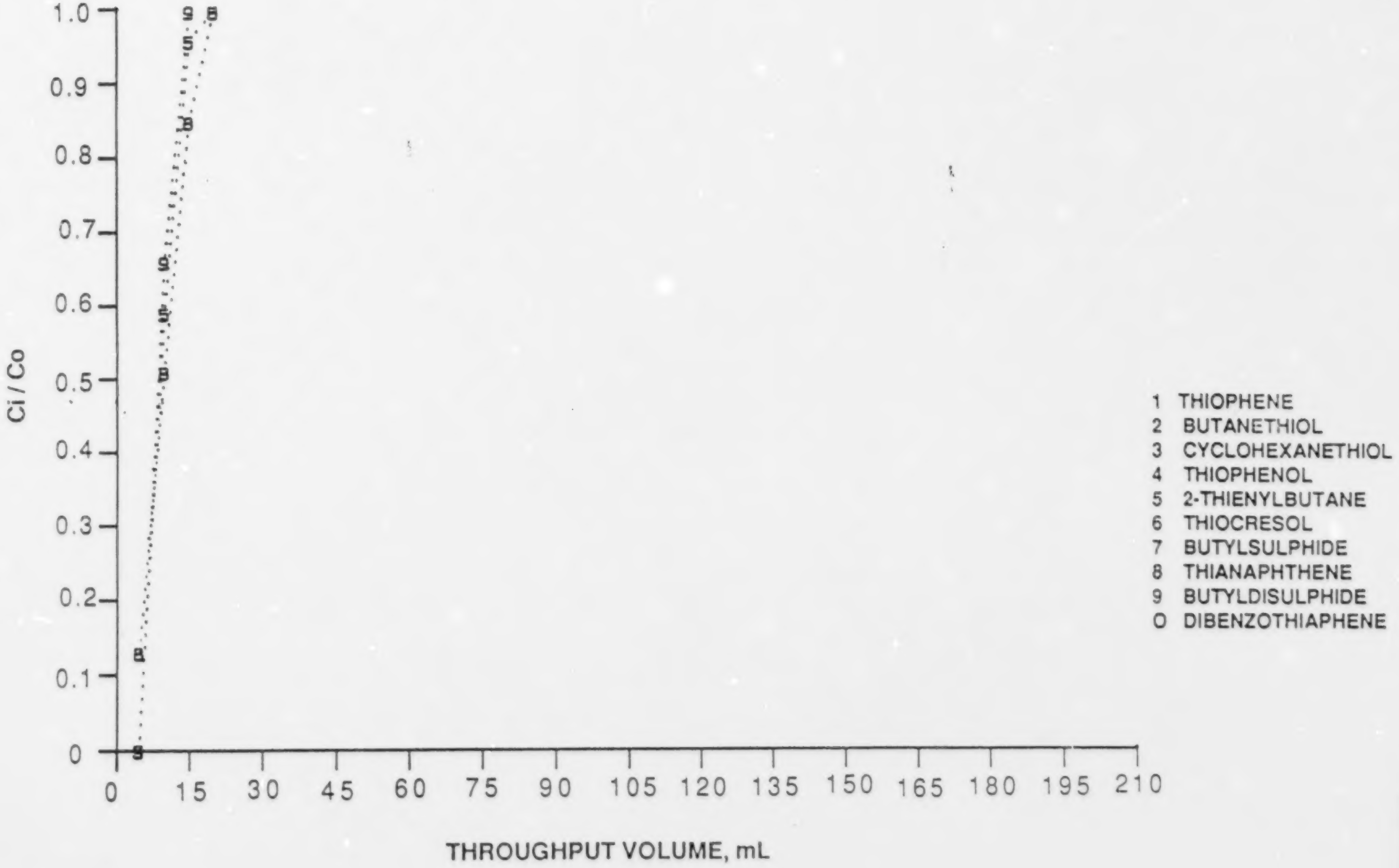

TABLE 5.8.3 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlyst XN-1010 Hydrogen

Sorbent Weight: 7.08 g Column Bed Volume: 5.9 mL Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5		0	0	0	0	0	0	0	0	0
10		0	0	0	0.55	0	0.54	0.44	0.51	0.40
15		0	0.53	0	0.98	0	0.96	0.91	0.94	0.88
20		0	0.83	0.50	1.0	0.30	1.0	1.0	0.98	0.93
25		0.2	0.89	0.65	0.97	0.54			0.81	0.74
30		0.4	0.93	0.76	1.0	0.70			1.0	1.0
35		0.6	0.97	0.84		0.79				
40		0.8	0.97	0.86		0.80				
45		0.9	0.99	0.90		0.87				
50		0.95	1.0	0.91		0.89				
55		1.0		0.95		0.95				
60				0.95		0.91				
65				0.99		0.97				
70				1.0		1.0				

COMMENTS:

The thiophene chromatographic peak is strongly overlapped by methanol.

FIGURE 5.8.3: Ci/Co FOR AMBERLYST XN-1010 HYDROGEN

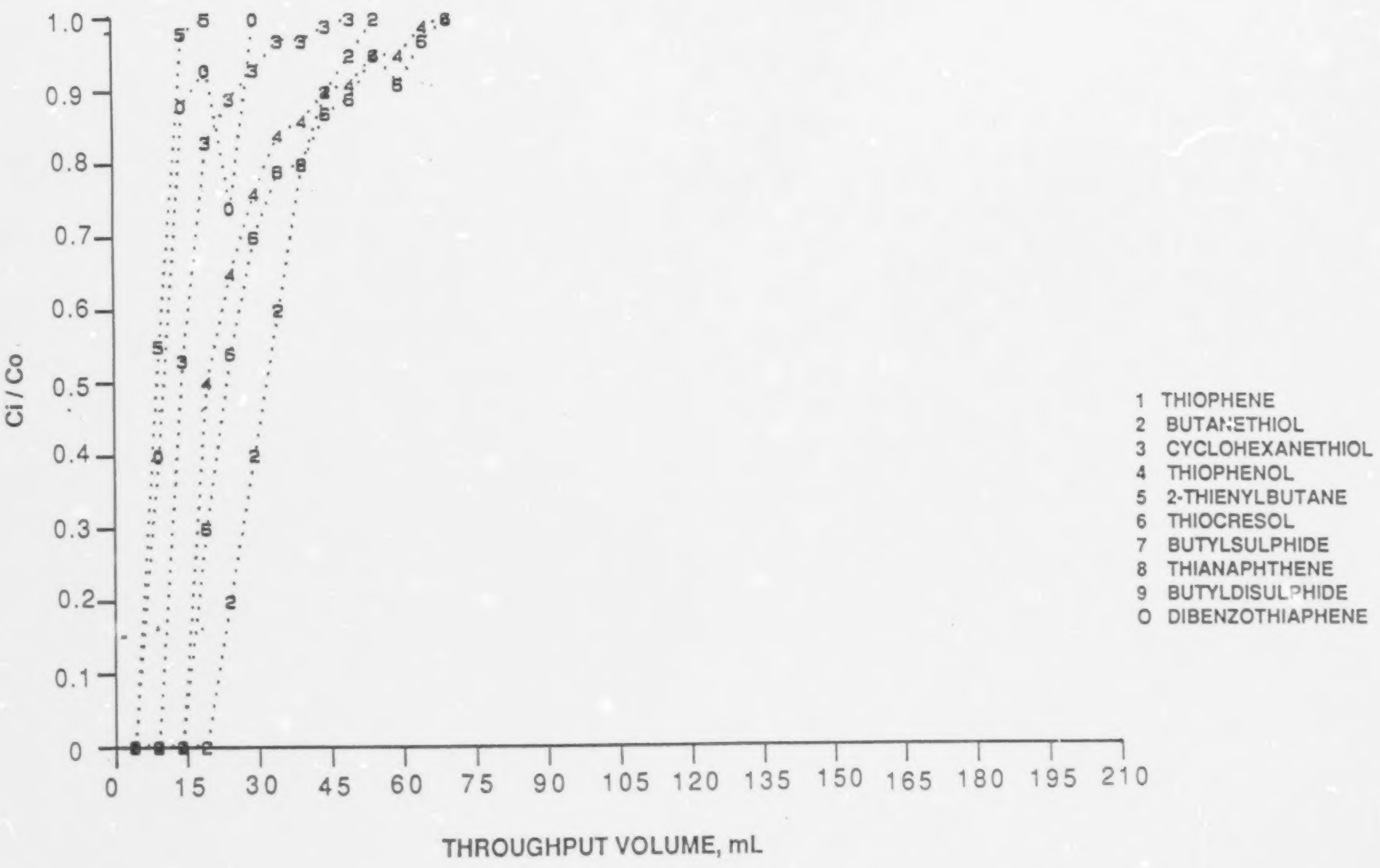

TABLE 5.8.4 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlyst XN-1010 Iron (III)

Sorbent Weight: 7.35 g Column Bed Volume: 6.1 mL Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5		0	0	0	0	0	0	0	0	0
10		0	0.30	0	0.75	0	0.77	0.63	0.77	0.57
15		0	0.43	0	1.0	0	1.0	0.97	1.0	0.92
20		0.19	0.42	0		0		0		0
25		0.26	0.39	0		0		0		0
30		0.20	0.48	0		0		0		0
35		0.27	0.43	0		0		0		0

COMMENTS:

Butanethiol and cyclohexanethiol did not increase and thiophenol and thiocresol did not breakthrough during the 25 BV duration of the test.

FIGURE 5.8.4: Ci/Co FOR AMBERLYST XN-1010 IRON (III)

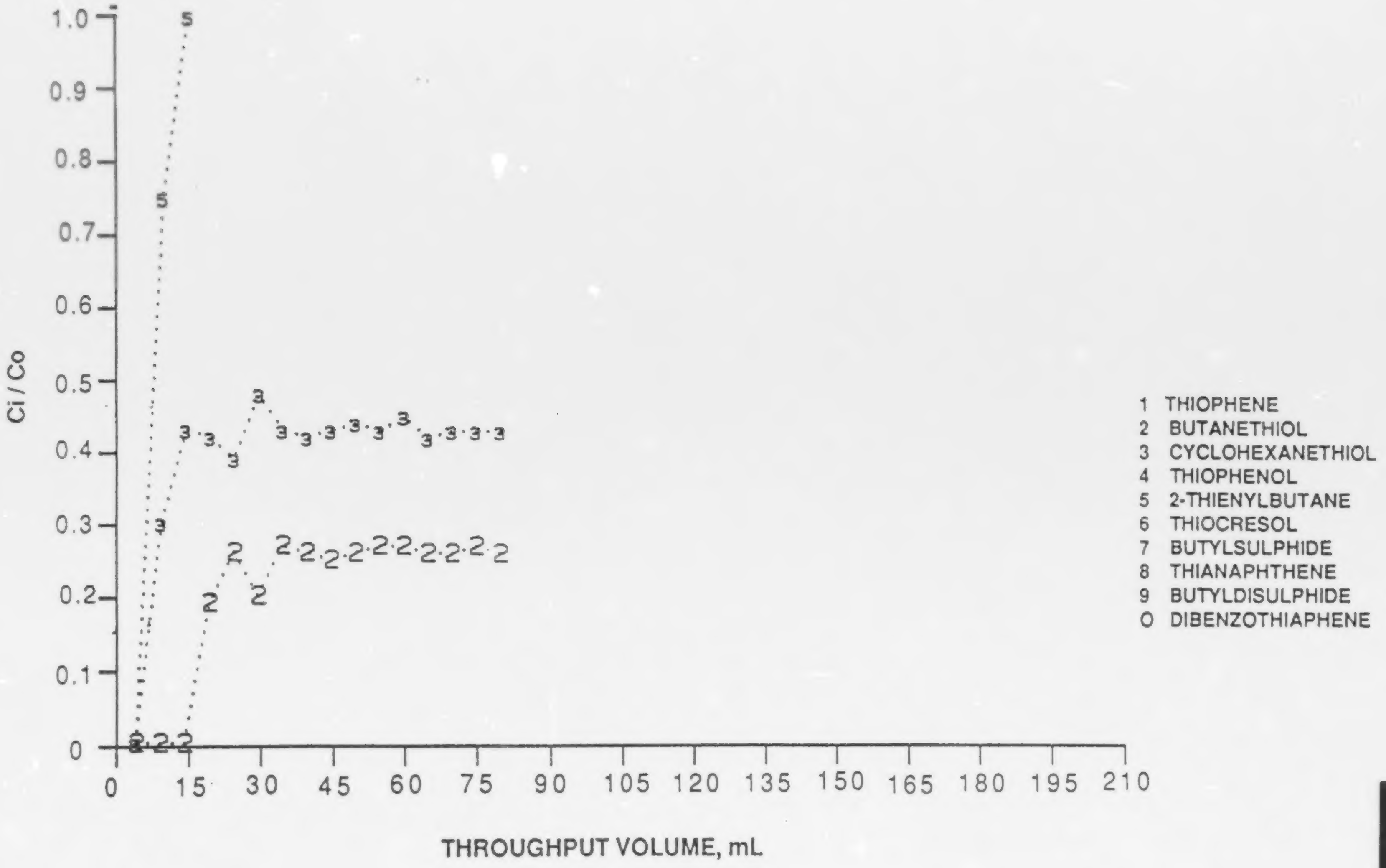

TABLE 5.8.5 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlyst XN-1010 Lanthanum

Sorbent Weight: 7.66 g Column Bed Volume: 6.2 mL Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5		0	0	0	0.07	0		0	0	0
10		0.3	0.52	0.3	0.72	0.35		0.05	0.65	0.57
15		0.70	0.76	0.59	0.99	0.77		0.76	0.84	0.81
20		0.75	0.83	0.75	1.0	0.93		0.85	0.97	0.94
25		0.95	0.94	0.88		1.0		0.99	1.0	1.0
30		1.00	0.99	0.89				1.0		
35			1.0	0.95						
40				1.0						

COMMENTS:

The thiophene chromatographic peak is strongly overlapped by methanol.

FIGURE 5.8.5: Ci/Co FOR AMBERLYST XN-1010 LANTHANUM

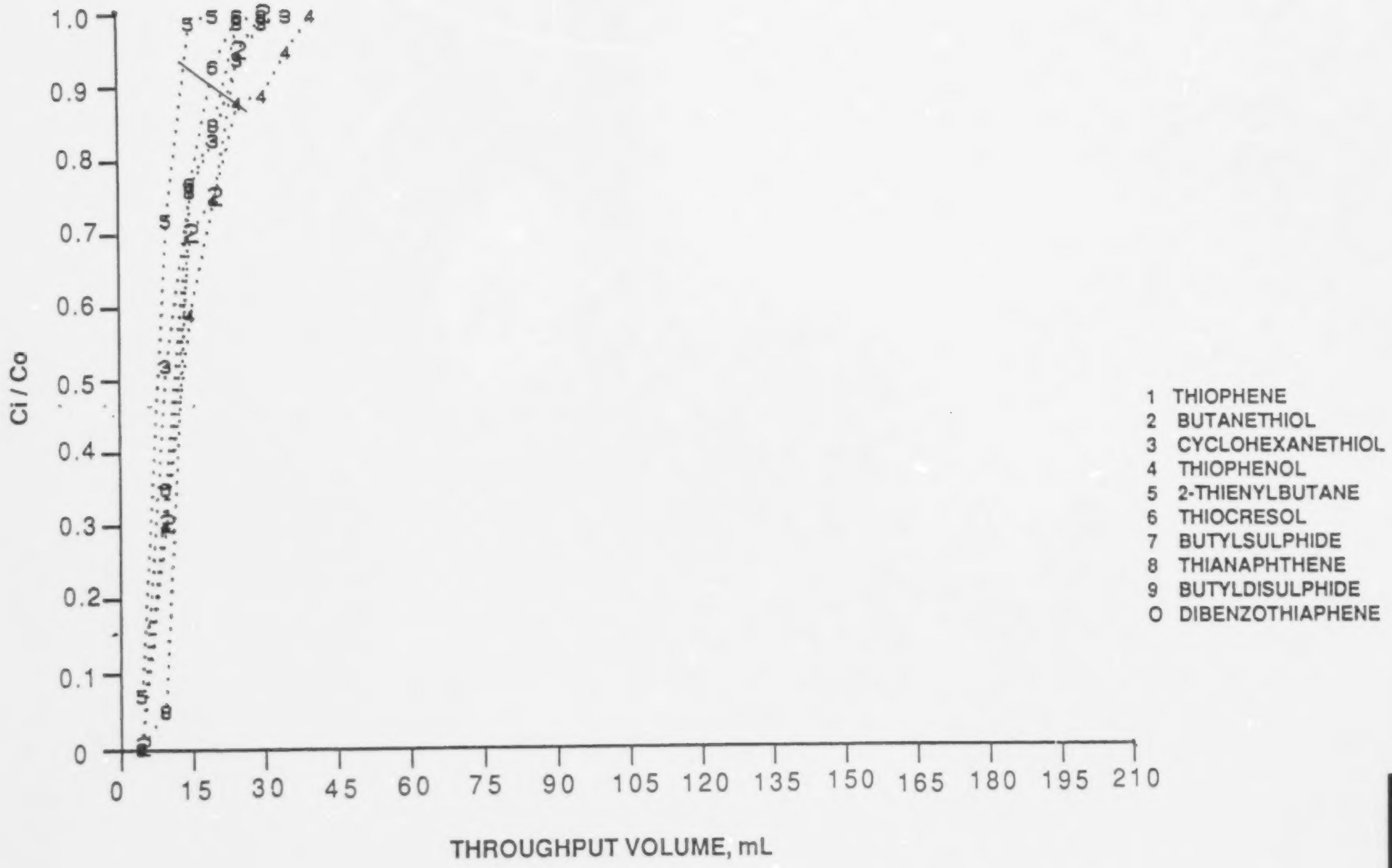

TABLE 5.8.6 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: XN-1010 Mercury

Sorbent Weight: 6.79 g Column Bed Volume: 5.7 mL Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5		0.25	0	0	0.04	0	0	0	0	0
10		0.25	0	0	0.04	0	0	0	0	0.02
15		0.26	0	0	0.58	0	0.03	0.48	0.57	0.47
20		0.26	0	0	0.91	0	0.03	0.91	0.77	0.89
25		0.26	0	0	0.96	0	0.37	0.98	0.73	0.97
30		0.26	0	0	0.97	0	0.48	1.0	0.73	1.0
35		0.26	0	0	0.96	0	0.57		0.70	
40		0.27	0	0	0.97	0	0.66		0.76	
45		0.15	0	0	0.96	0	0.71		0.90	
50		0.39	0.23	0	0.97	0	0.80		0.95	
55		0.47	0.28	0	0.97	0	0.95		0.93	
60		0.52	0.24	0	0.97	0	0.93		0.93	
65		0.53	0.29	0	0.95	0	0.98		0.94	
70		0.54	0.32	0	0.96	0	0.99		0.96	
75		0.69	0.57	0.11	0.97	0.09	1.0		0.94	
80		0.68	0.63	0.17	0.98	0.10			0.95	
85		0.69	0.77	0.36	1.0	0.23			0.96	
90		0.73	0.80	0.43		0.33			0.97	
95		0.89	0.92	0.80		0.68			0.98	
100		0.85	0.91	0.79		0.68			0.97	
105		0.88	0.92	0.82		0.72			0.98	
110		0.86	0.92	0.84		0.75			0.97	
115		0.86	0.92	0.85		0.77			0.97	
120		0.88	0.92	0.93		0.81			0.97	
125		0.88	0.94	0.93		0.83			0.98	
130		0.90	0.94	0.94		0.86			0.98	
135		0.87	0.93	0.96		0.87			1.0	

COMMENTS:

The thiophene chromatographic peak is strongly overlapped by methanol.

FIGURE 5.8.6: Ci/Co FOR AMBERLYST XN-1010 MERCURY

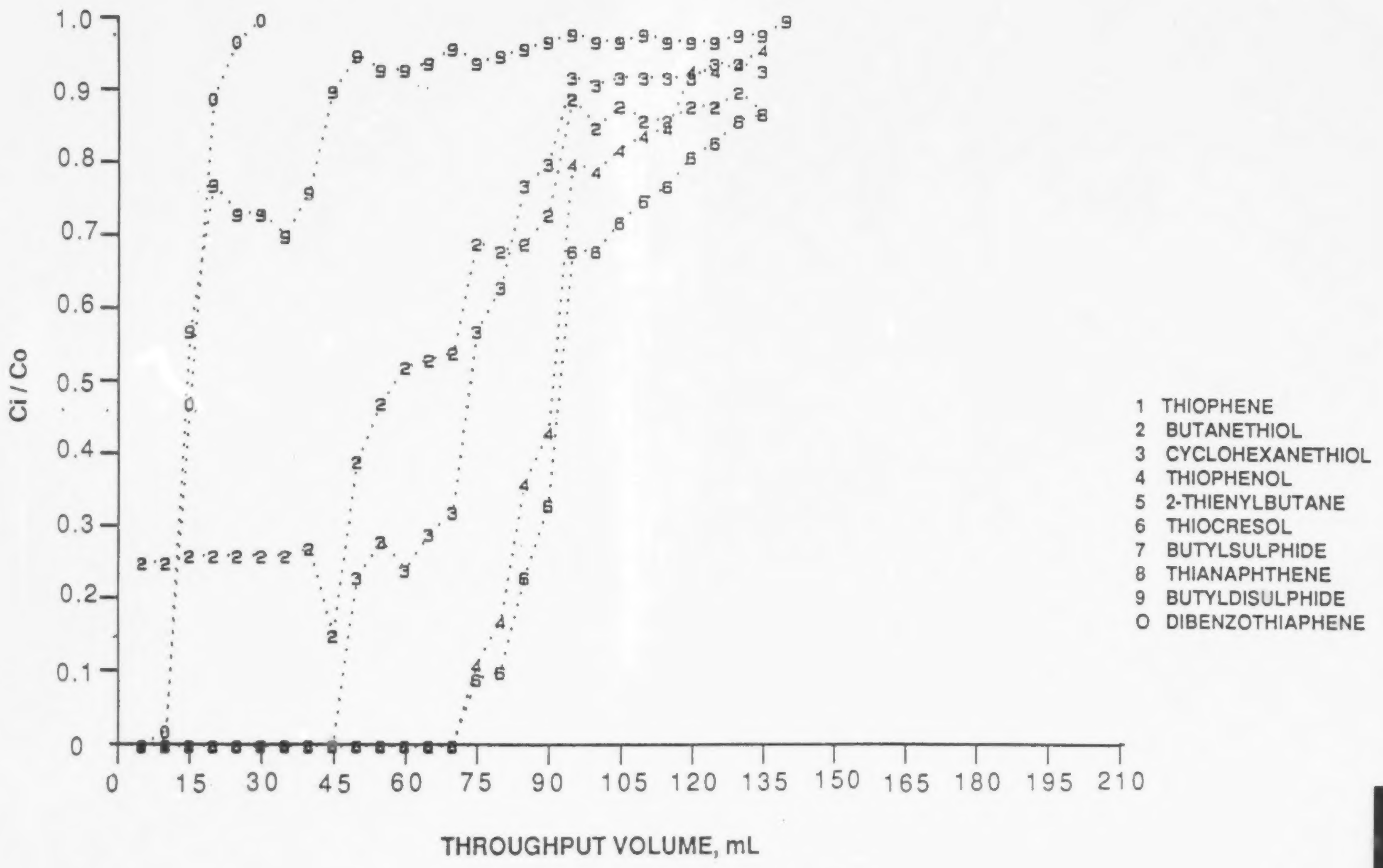

TABLE 5.8.7 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlyst XN-1010 Nickel

Sorbent Weight: 7.14 g Column Bed Volume: 6.2 mL Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5		0.25	0	0	0	0	0	0	0	0
10		0.25	0	0	0.05	0	0.04	0.03	0.04	0.03
15		0.46	0.60	0.38	0.66	0.40	0.70	0.56	0.68	0.55
20		0.61	0.81	0.70	0.90	0.67	0.91	0.86	0.81	0.78
25		0.75	0.98	0.93	1.0	0.96	1.0	1.0	1.0	1.0
30		0.83	1.0	0.98		1.0				
35		0.91		1.0						
40		0.89								
45		0.94								
50		0.96								
55		0.93								
60		0.98								
65		1.0								

COMMENTS:

The thiophene chromatographic peak is strongly overlapped by methanol.

FIGURE 5.8.7: Ci/Co FOR AMBERLYST XN-1010 NICKEL

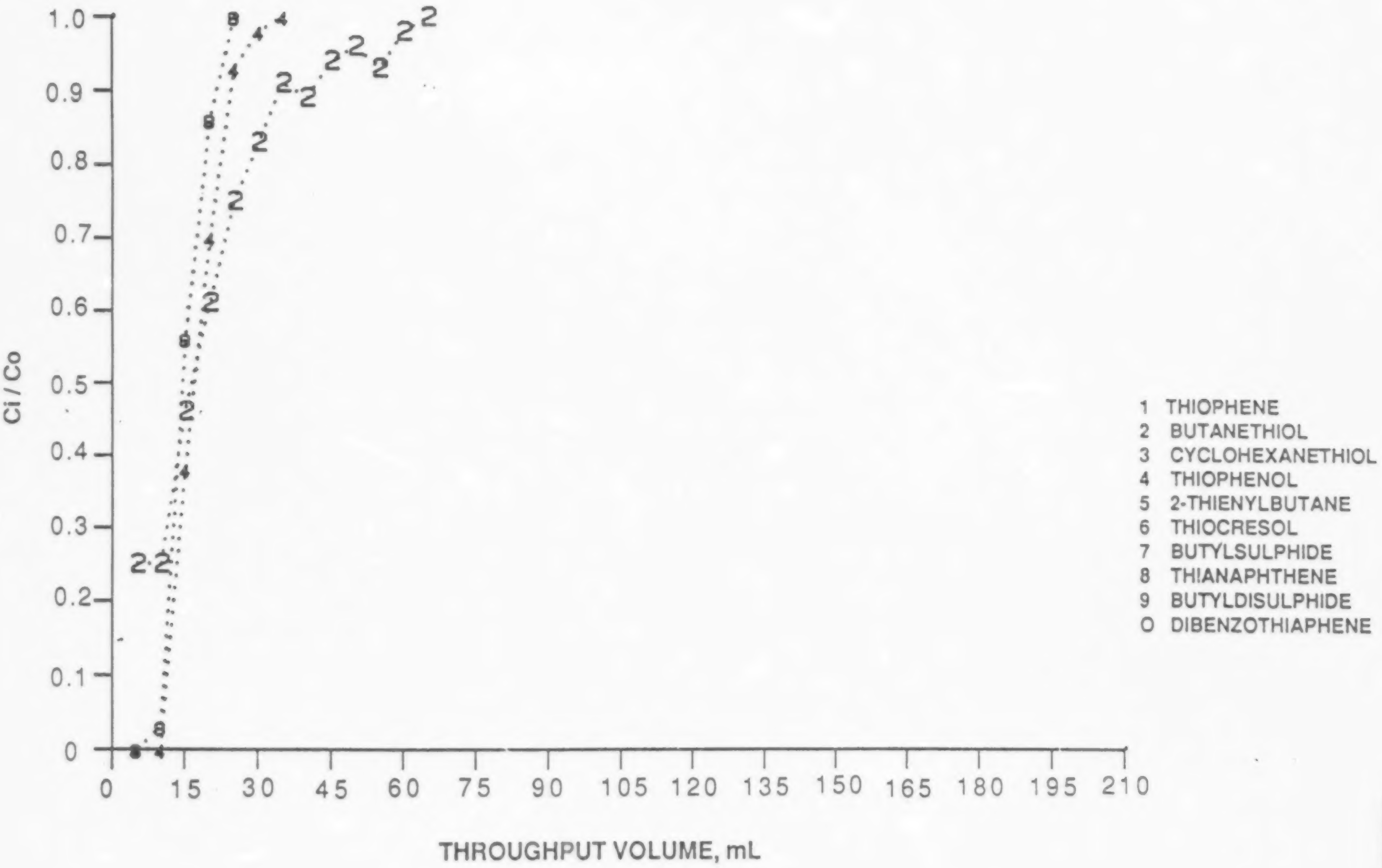

TABLE 5.8.8 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlyst XN-1010 Strontium

Sorbent Weight: 7.58 g Column Bed Volume: 5.8 mL Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5		0	0	0	0	0	0	0	0	0
10		0	0	0	0	0	0	0.07	0	0.07
15		0.19	0.40	0.19	0.53	0.19	0.54	0.46	0.50	0.51
20		0.59	0.80	0.62	0.89	0.59	0.90	0.86	0.89	0.86
25		0.67	0.84	0.71	0.84	0.65	0.85	0.81	0.86	0.86
30		0.84	0.95	0.85	0.94	0.72	0.94	0.86	0.88	0.93
35		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

COMMENTS:

The thiophene chromatographic peak is strongly overlapped by methanol.

FIGURE 5.8.8: Ci/Co FOR AMBERLYST XN-1010 STRONTIUM

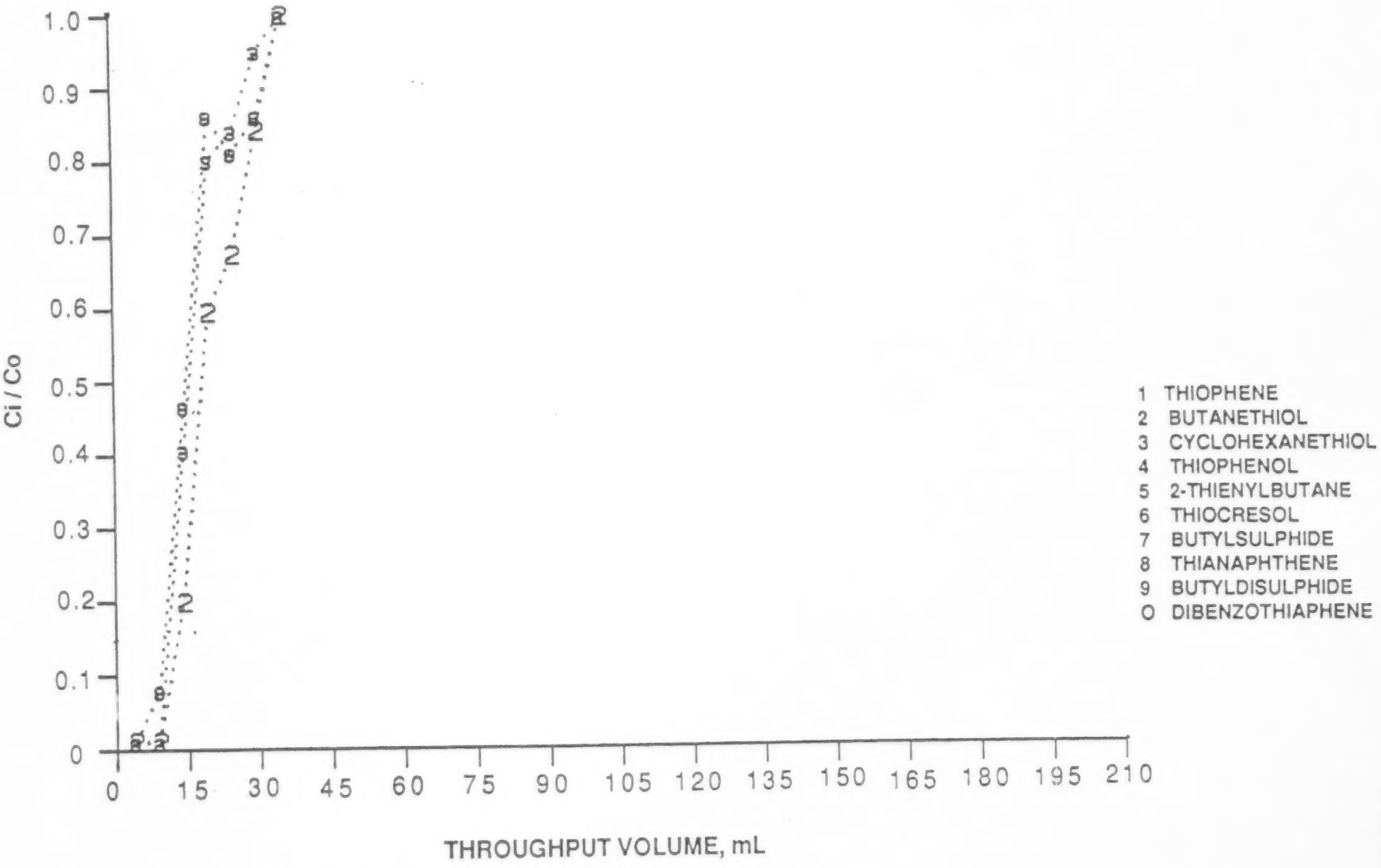

TABLE 5.8.9 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlyst XN-1010 Titanium

Sorbent Weight: 7.50 g Column Bed Volume: 6.1 mL Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5		0	0	0	0	0	0	0	0	0
10		0	0	0	0	0	0	0	0	0
15		0	0.20	0	0.42	0	0.48	0.34	0.55	0.37
20		0.26	0.73	0.42	1.0	0.36	1.0	0.92	1.0	1.0
25		0.51	0.83	0.64		0.56		0.93		
30		0.73	1.0	0.86		0.79		1.0		
35		0.82		0.98		0.92				
40		0.84		0.98		0.93				
45		0.86		1.0		0.95				
50		0.81				0.92				
55		1.0				1.0				

COMMENTS:

The thiophene chromatographic peak is strongly overlapped by methanol.

FIGURE 5.8.9: Ci/Co FOR AMBERLYST XN-1010 TITANIUM

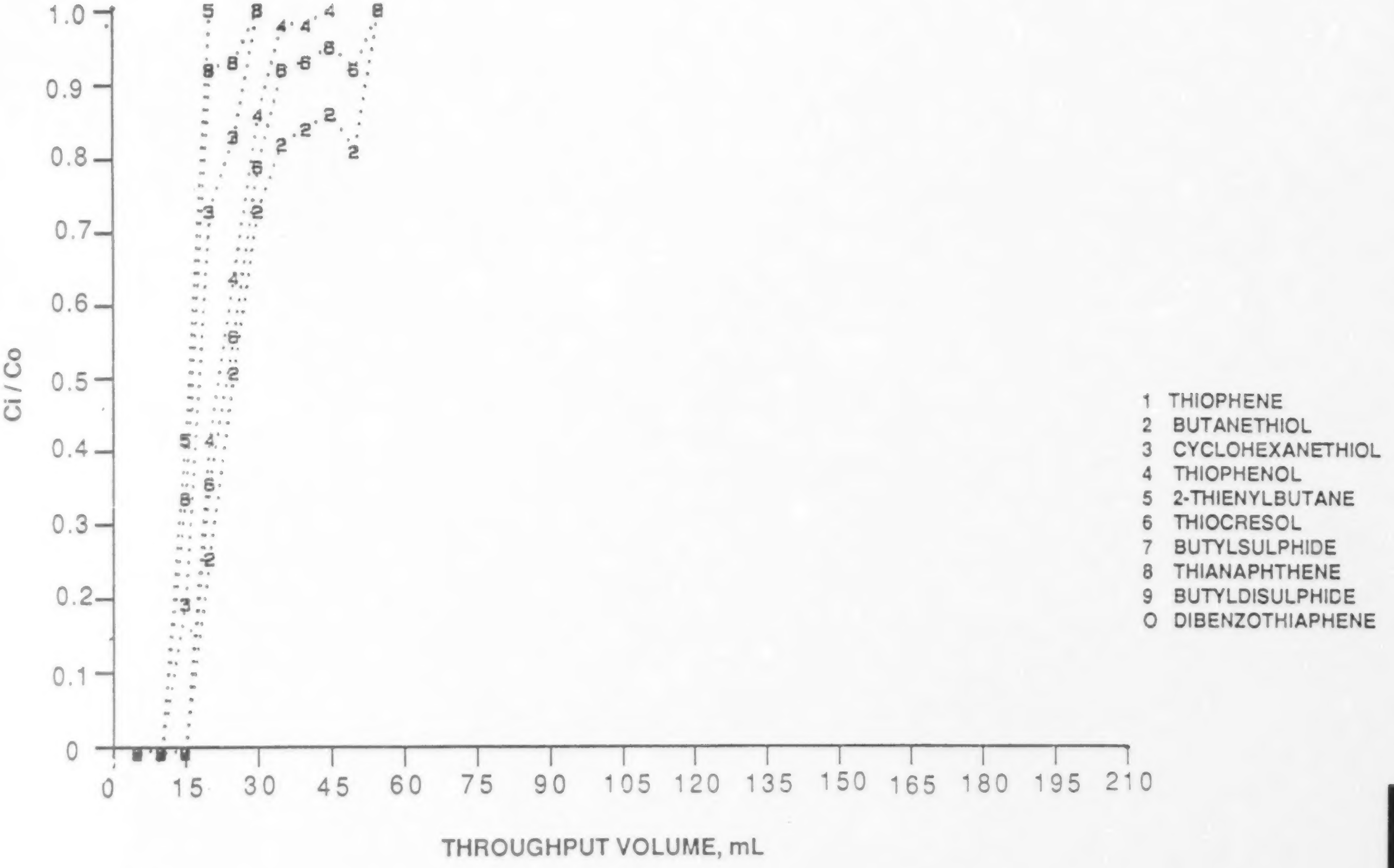

TABLE 5.8.10 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlyst XN-1010 Vanadium

Sorbent Weight: 7.52 g Column Bed Volume: 5.5 mL Flowrate: 0.46 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5		0	0	0	0	0	0	0	0	0
10		0.06	0	0	0	0	0	0	0	0
15		0.11	0	0	0.04	0	0	0	0	0
20		0.18	0.52	0.20	0.60	0.14	0.73	0.62	0.70	0.62
25		0.62	0.84	0.57	0.96	0.52	1.0	0.96	1.0	1.0
30		0.68	1.0	0.74	1.0	0.62		1.0		
35		0.66		0.81		0.74				
40		0.67		0.90		0.87				
45		0.68		1.0		1.0				
50		0.78								
55		1.0								

COMMENTS:

The thiophene chromatographic peak is strongly overlapped by methanol.

FIGURE 5.8.10: Ci/Co FOR AMBERLYST XN-1010 VANADIUM (III)

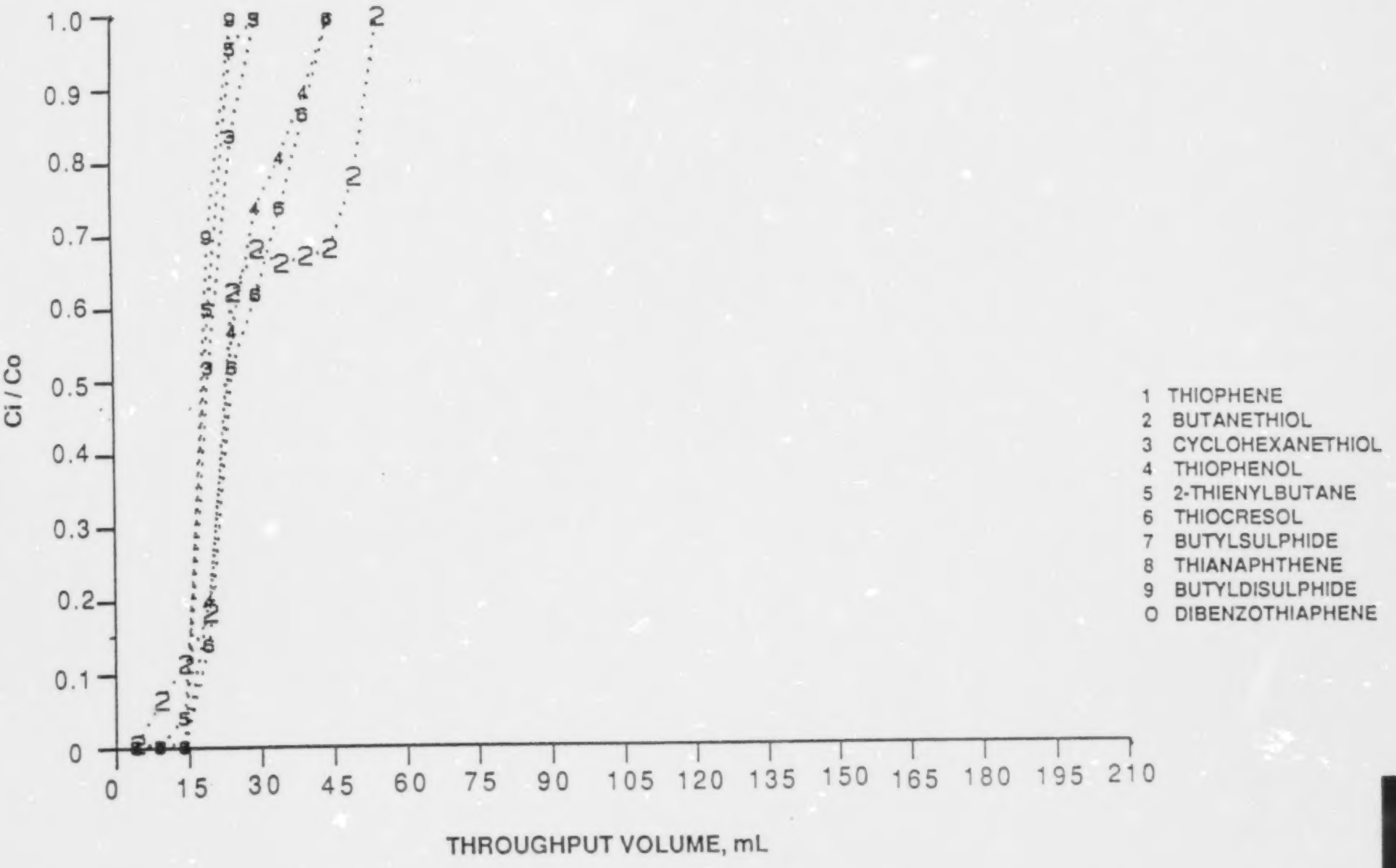

TABLE 5.8.11 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlyst XN-1010 Zinc

Sorbent Weight: 6.70 g Column Bed Volume: 9.0 mL Flowrate: 0.75 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5		0.18	0	0	0	0	0	0	0	0
10		0.28	0.03	0.03	0.05	0	0.05	0.04	0.05	0.04
15		0.35	0.49	0.26	0.60	0.25	0.60	0.52	0.63	0.50
20		0.65	0.83	0.63	0.93	0.60	0.92	0.89	0.94	0.93
25		0.75	0.91	0.77	0.98	0.72	0.97	0.97	0.99	0.99
30		0.78	0.93	0.80	0.99	0.76	0.98	0.98	1.0	0.99
35		0.80	0.94	0.84	0.99	0.79	0.98	0.99		1.0
40		0.83	0.95	0.85	1.0	0.82	0.99	1.0		
45		0.83	0.95	0.87		0.83				
50		0.84	0.95	0.87		0.84				
55		0.84	0.96	0.87		0.85				
60		0.84	0.96	0.89		0.86				
65					SAMPLES WERE LOST					
70										
75		0.87	0.97	0.92		0.89				
80		0.88	0.97	0.92		0.90				
85		0.89	0.98	0.93		0.91				
90		0.90	1.0	0.95		0.92				
95		0.90		0.95		0.92				
100		0.90		0.96		0.93				
105		0.91		0.95		0.93				
110		0.90		0.95		0.93				
115		0.92		0.96		0.94				
120		0.91		0.99		0.93				
125		0.90		1.0		0.93				
130		0.89				0.94				
135		0.90				0.93				
140		0.91				0.94				
145		0.92				0.94				

COMMENTS:

The thiophene chromatographic peak is strongly overlapped by methanol.

FIGURE 5.8.11: Ci/Co FOR AMBERLYST XN-1010 ZINC

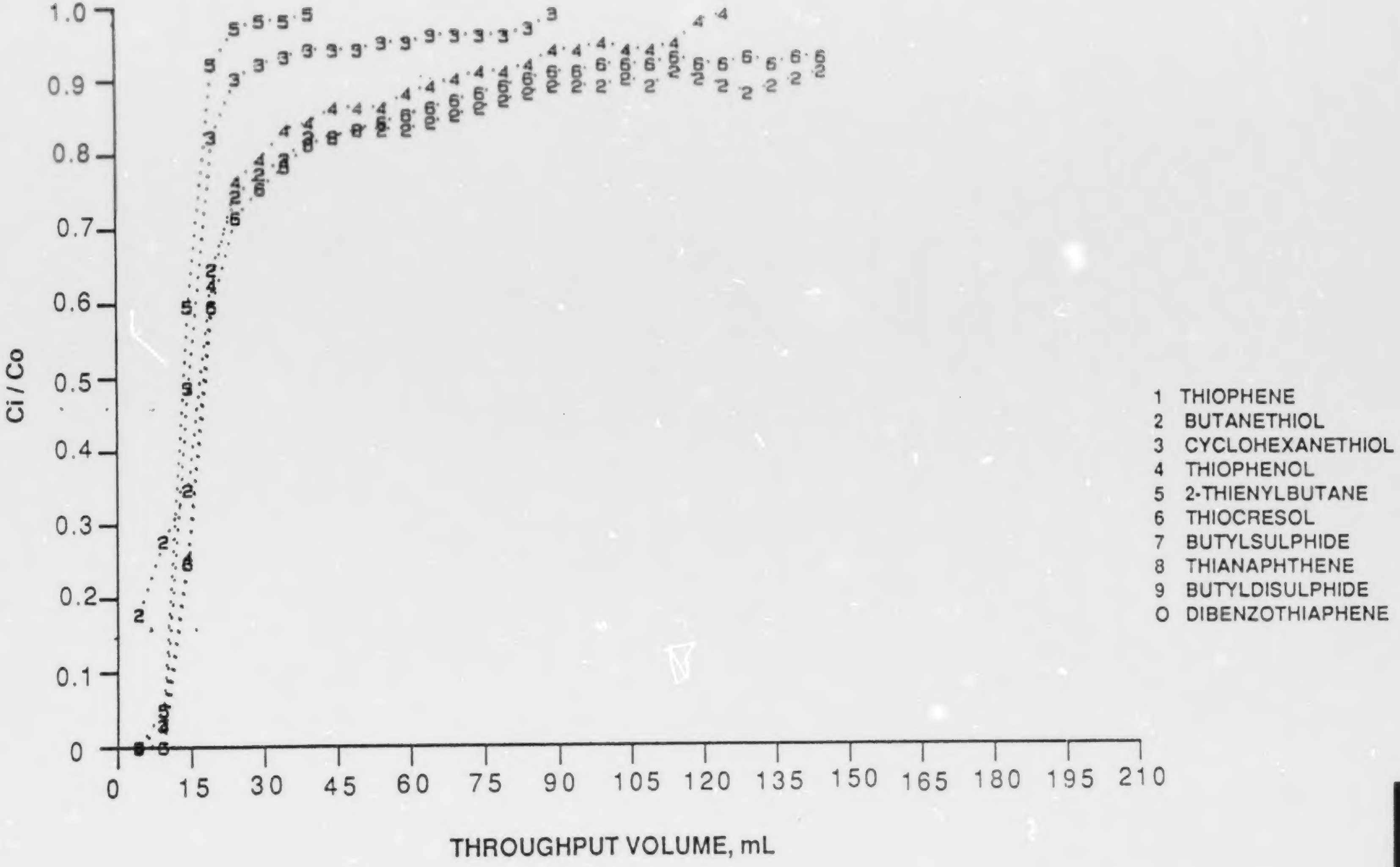

TABLE 5.9.1 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlyst 15 Barium

Sorbent Weight: 7.73 g Column Bed Volume: 5.7 mL Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5		0	0	0	0	0	0	0	0	0
10		0	0	0	0	0	0	0	0	0
15		0.16	0.22	0.14	0.23	0.15	0.24	0.18	0.22	0.19
20		0.88	0.84	0.77	0.83	0.78	0.84	0.79	0.79	0.78
25		1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.95	0.96
30									1.0	1.0
35										

COMMENTS:

The thiophene chromatographic peak is strongly overlapped by methanol.

FIGURE 5.9.1: Ci/Co FOR AMBERLYST 15 BARIUM

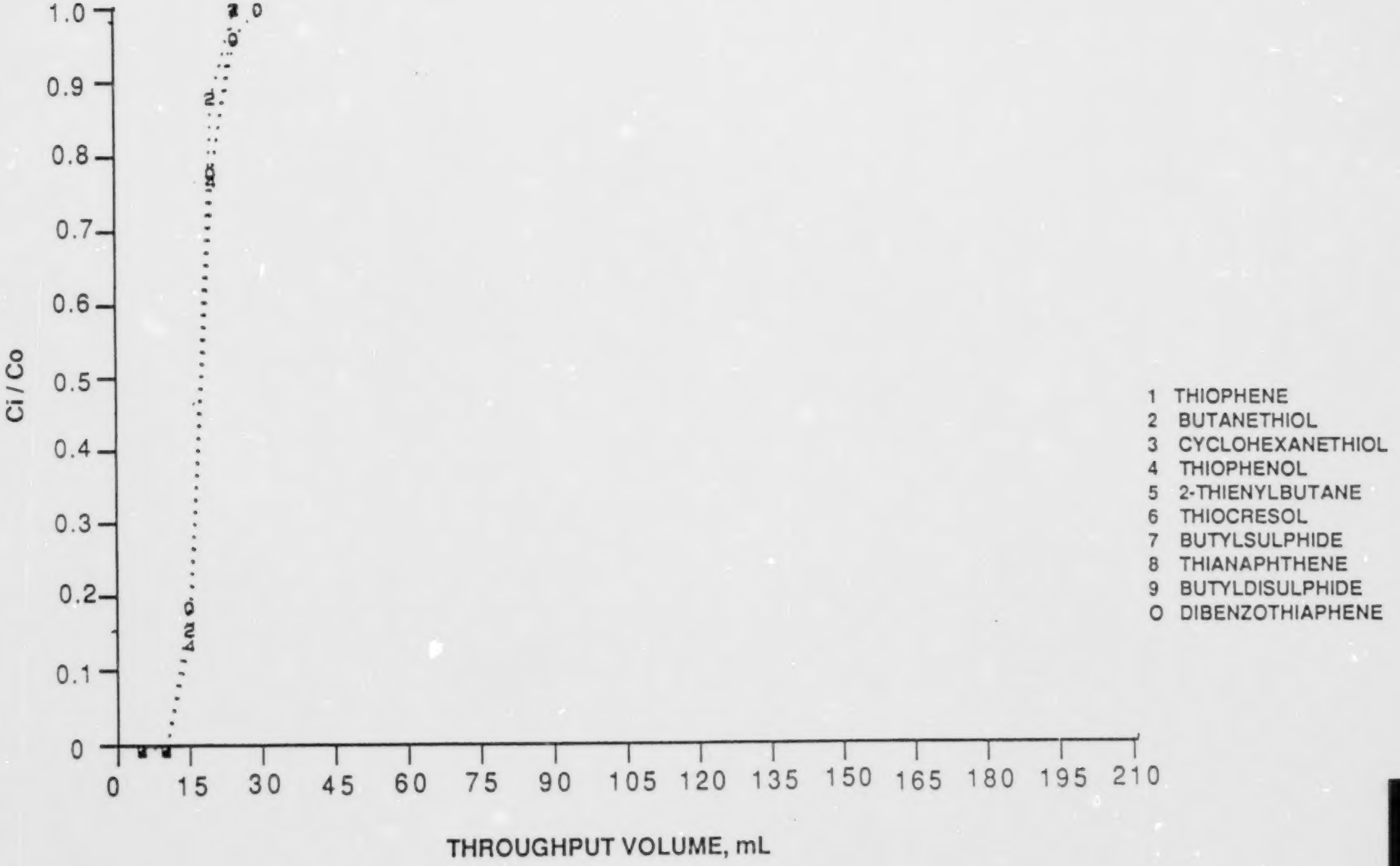

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TABLE 5.9.2 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlyst 15 Copper

Sorbent Weight: 7.74 g Column Bed Volume: 5.8 mL Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.32	0.27	0	0.04	0	0	0	0	0	0
10	0.35	0.28	0	0.04	0.06	0	0.05	0.05	0.06	0.04
15	0.66	0.28	0	0.04	0.60	0	0.57	0.84	0.67	0.53
20	0.90	0.07	0	0	0.95	0	0.93	0.95	1.0	0.94
25	0.98	0.20	0	0	1.0	0	0.98	0.99		0.98
30	0.98	0.19	0	0		0	0.99	1.0		0.99
35	0.98	0.19	0	0		0	0.97			0.97
40	0.97	0.27	0	0		0	0.98			0.97
45	1.0	0.19	0	0		0	0.98			0.98
50		0.19	0	0		0	1.0			1.0
55		0.27	0	0		0				
60		0.27	0	0		0				
65		0.19	0	0		0				
70		0.19	0	0		0				
75		0.27	0	0		0				
80		0.20	0	0		0				
85		0.28	0	0		0				
90		0.19	0	0		0				
95		0.20	0	0		0				
100		0.26	0	0		0				
105		0.19	0	0		0				
110		0.19	0	0		0				
115		0.20	0	0		0				
120		0.20	0	0		0				
125		0.20	0	0		0				
130		0.27	0	0		0				
135		0.28	0	0		0				
140		0.28	0	0		0				
145		0.20	0	0		0				
150		0.20	0	0		0				

COMMENTS:

Cyclohexane, thiophenol and thiocresol did not break through during the test.

FIGURE 5. 9. 2:   Ci/Co FOR AMBERLYST 15 COPPER

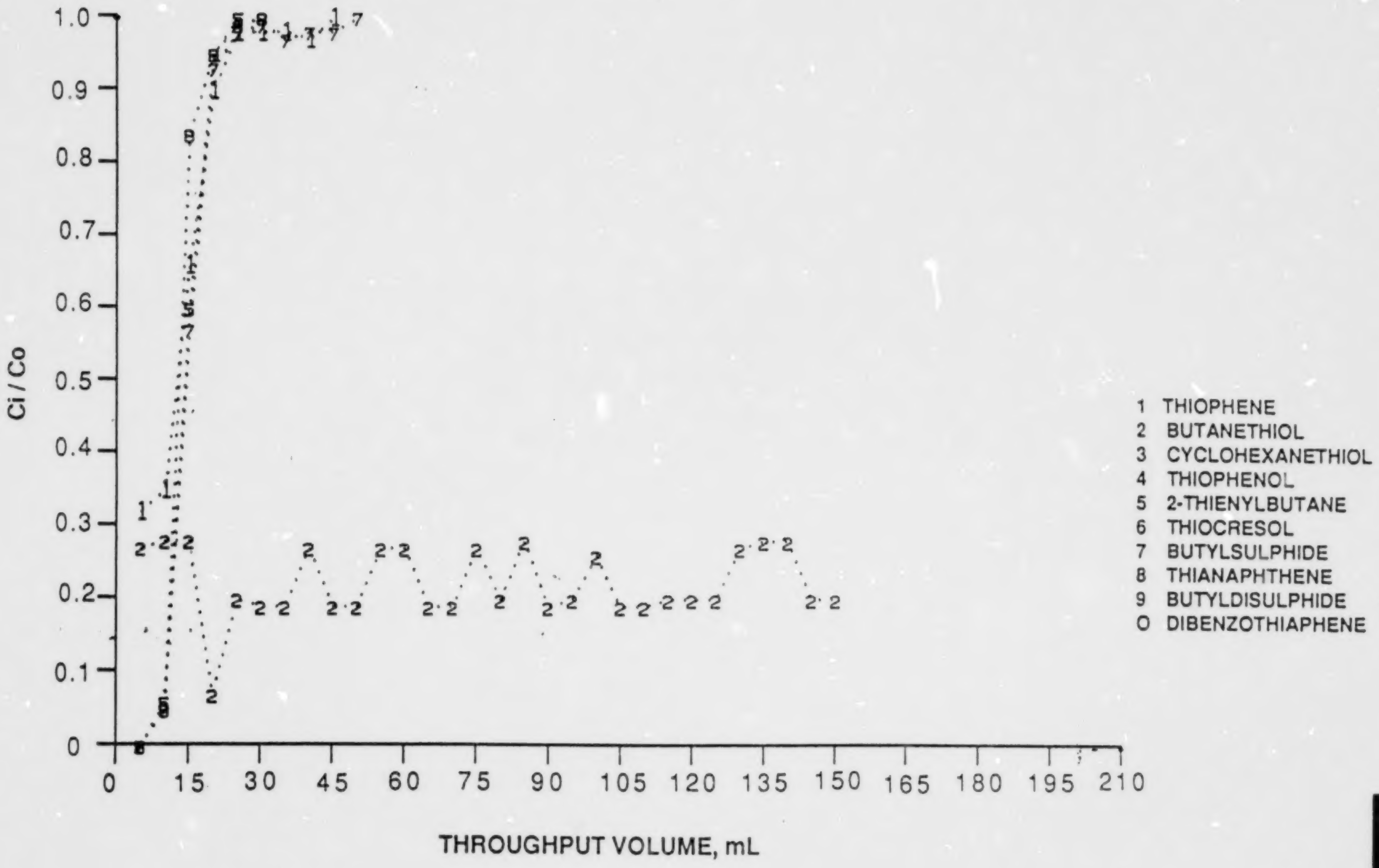

TABLE 5.9.3 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlyst 15 Iron (III)

Sorbent Weight: 7.23 g   Column Bed Volume: 6.0 mL   Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5		0.03	0.08	0	0.16	0	0.15	0.12	0.18	
10		0.37	0.45	0.03	0.75	0.04	0.69	0.68	0.71	
15		0.46	0.59	0.03	0.90	0.04	0.90	0.89	0.80	
20		0.49	0.59	0.03	0.86	0.04	0.85	0.86	0.72	
25		0.49	0.63	0.03	0.92	0.04	0.91	0.92	0.94	
30		0.48	0.58	0.03	0.83	0.04	0.82	0.83	1.0	
35		0.52	0.62	0.04	0.90	0.04	0.89	0.89		
40		0.50	0.62	0.05	0.88	0.06	0.86	0.89		
45		0.53	0.64	0.14	0.93	0.11	0.87	0.93		
50		0.58	0.73	0.04	1.0	0.05	1.0	1.0		
55		0.59	0.66	0.04		0.04				
60		0.58	0.69	0.04		0.04				
65		0.59	0.65	0.03		0.03				
70		0.59	0.68	0.04		0.04				
75		0.61	0.68	0.04		0.04				
80		0.61	0.70	0.06		0.06				
85		0.57	0.67	0.07		0.07				
90		0.60	0.63	0.13		0.10				
95		0.63	0.77	0.07		0.07				

COMMENTS:

The thiophene chromatographic peak is strongly overlapped by methanol.

FIGHURE 5.9.3: Ci/Co FOR AMBERLYST 15 IRON (III)

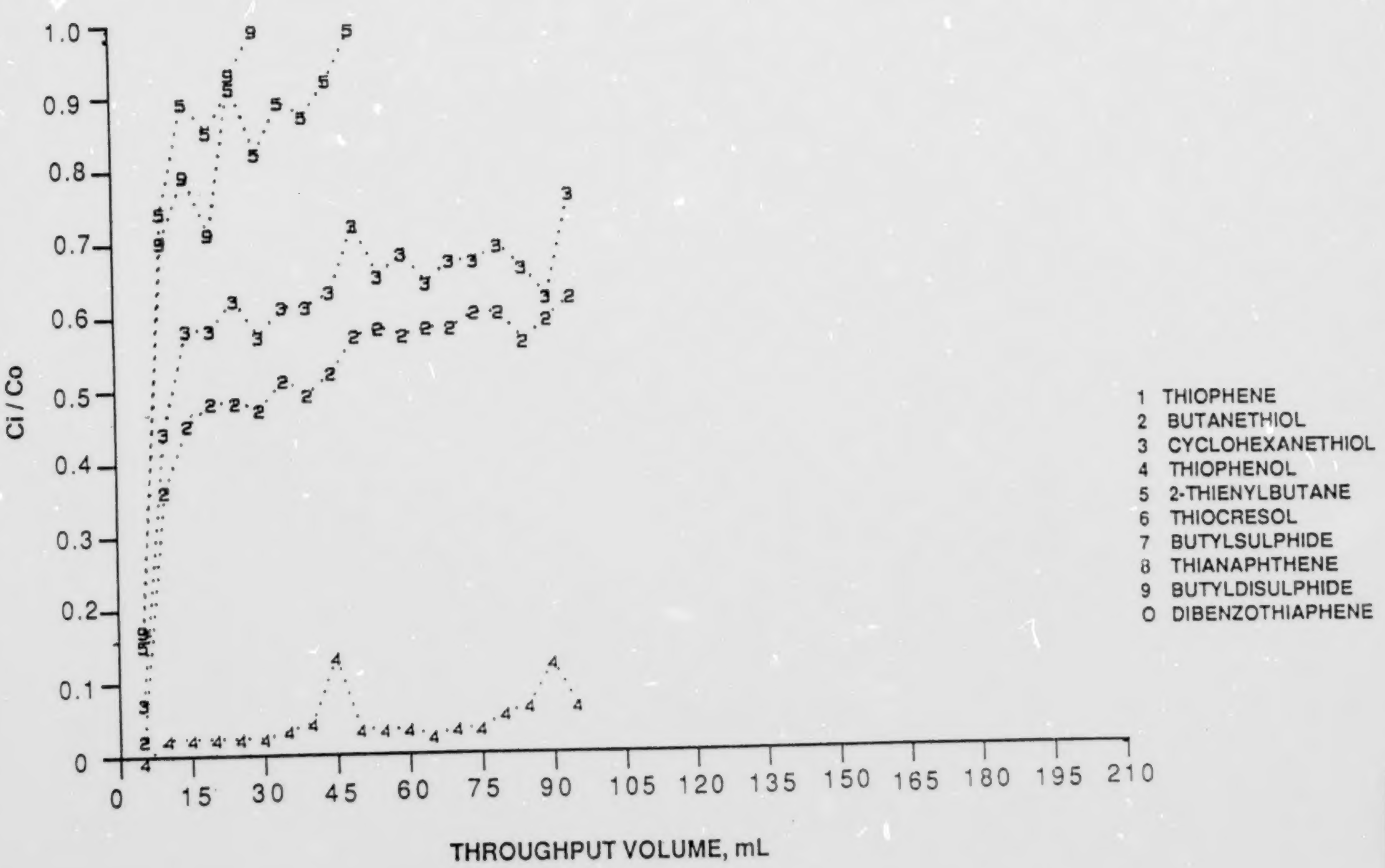

TABLE 5.9.4 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlyst 15 Hydrogen

Sorbent Weight: 6.79 g Column Bed Volume: 6.4 mL Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5		0.06	0	0.04	0	0	0	0	0	0
10		0.07	0	0.04	0	0	0	0	0	0
15		0.22	0.35	0.23	0.40	0.25	0.41	0.34	0.43	0.34
20		0.77	0.84	0.79	0.88	0.81	0.88	0.91	0.94	0.91
25		0.89	0.93	0.91	0.95	0.92	0.95	0.99	0.99	0.98
30		0.94	0.94	0.93	0.96	0.93	0.96	0.99	1.0	0.99
35		1.0	1.0	0.97	1.0	0.98	1.0	1.0		1.0
40				1.0		1.0				

COMMENTS:

The thiophene chromatographic peak is strongly overlapped by methanol.

FIGURE 5.9.4: Ci/Co FOR AMBERLYST 15 HYDROGEN

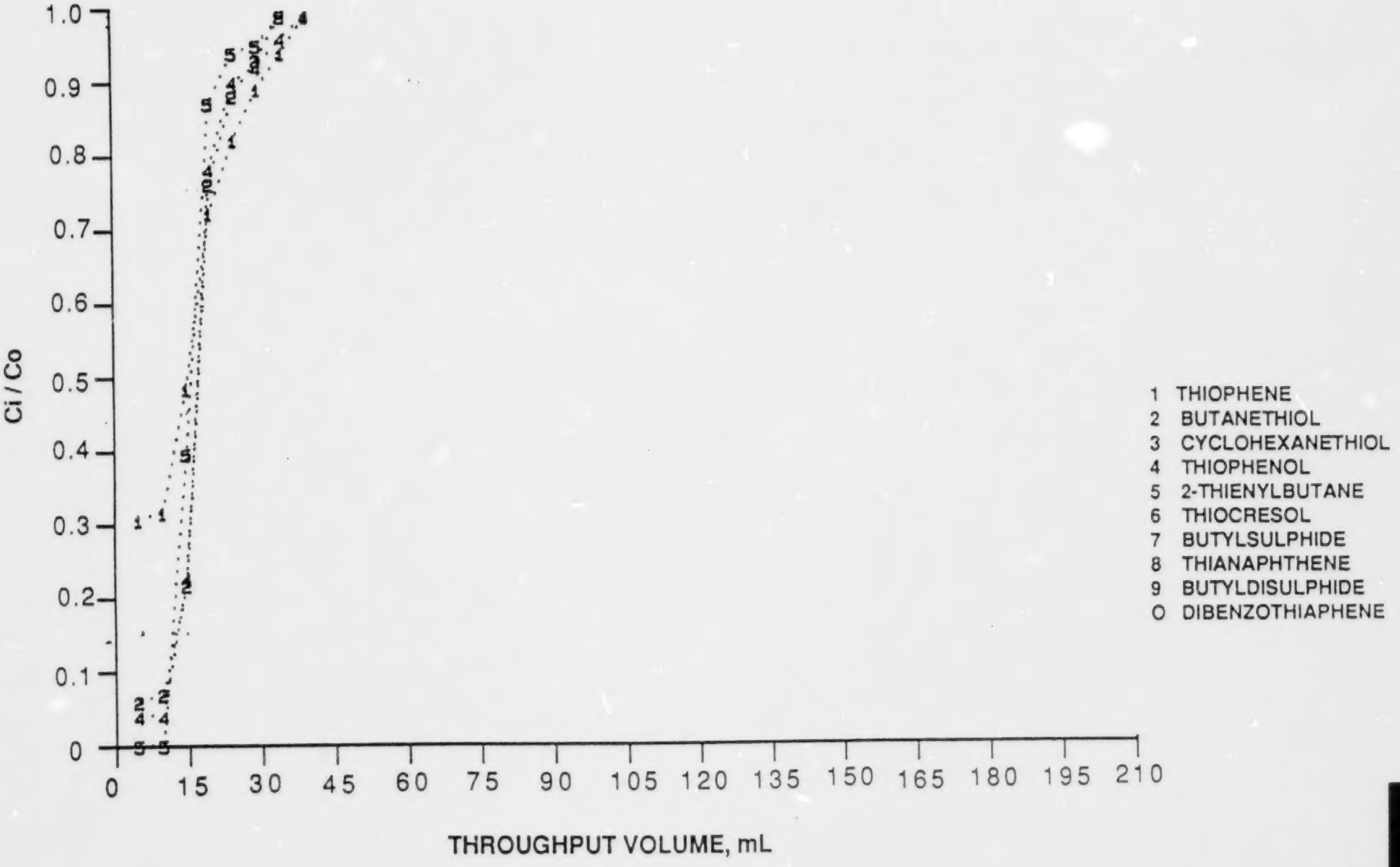

TABLE 5.9.5 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlyst 15 Lanthanum

Sorbent Weight: 7.25 g Column Bed Volume: 5.9 mL Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5		0.07	0	0	0	0	0	0	0	0
10		0.07	0	0	0.03	0	0.03	0.03	0	0.03
15		0.52	0.51	0.41	0.54	0.42	0.53	0.49	0.55	0.53
20		0.97	0.87	0.82	0.87	0.81	0.86	0.87	0.89	0.96
25		1.0	0.94	0.91	0.96	0.92	0.95	0.98	1.0	1.0
30			1.0	1.0	1.0	1.0	1.0	1.0		

COMMENTS:

The thiophene chromatographic peak is strongly overlapped by methanol.

FIGURE 5.9.5: Ci/Co FOR AMBERLYST 15 LANTHANUM

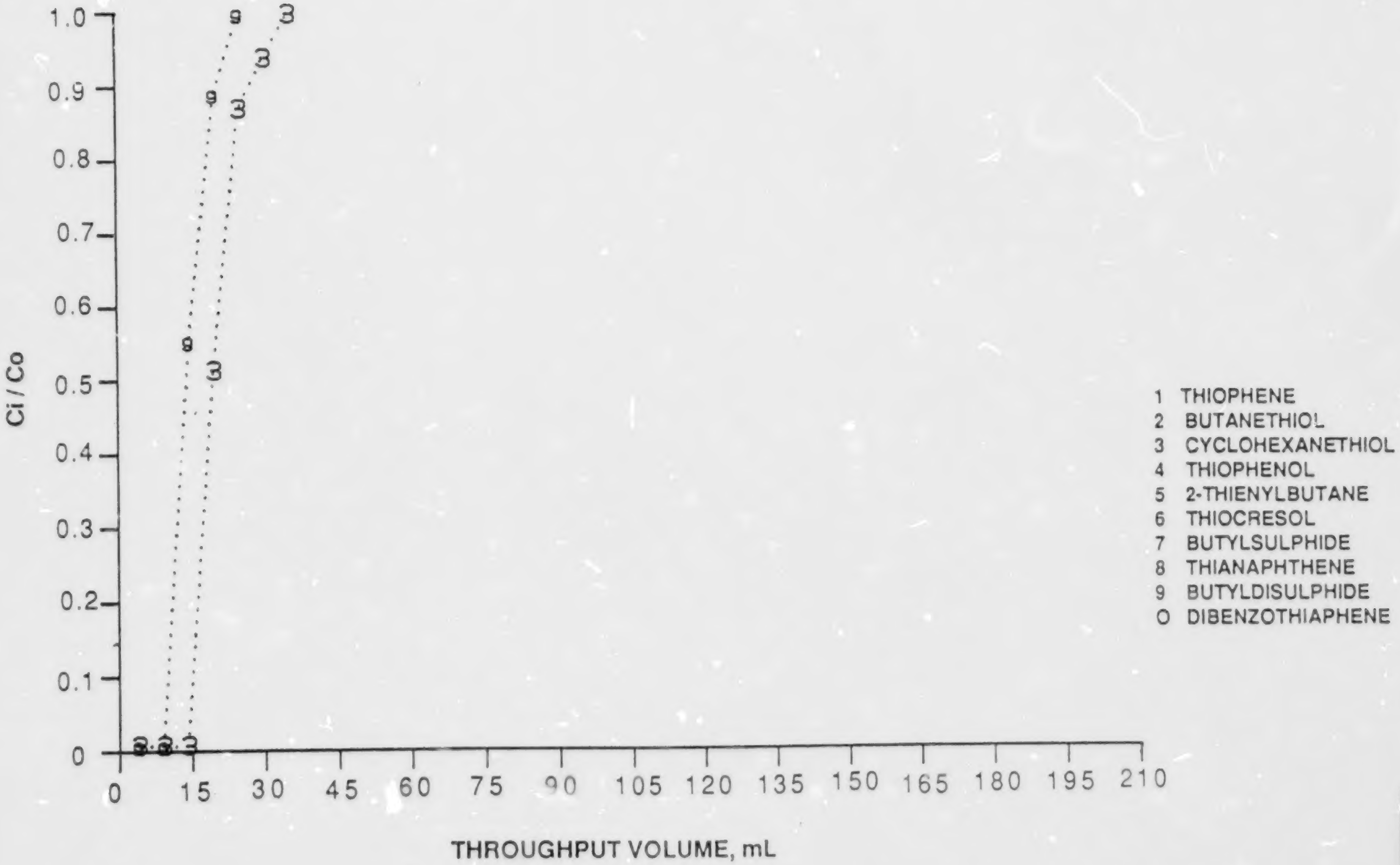

TABLE 5.9.6 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlyst 15 Mercury

Sorbent Weight: 7.34 g Column Bed Volume: 5.8 mL Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5		0	0	0	0	0	0	0	0	0
10		0	0	0	0	0	0	0	0	0
15		0.10	0.16	0.08	0.19	0.10	0.20	0.14	0.20	0.15
20		0.71	0.80	0.65	0.89	0.75	0.92	0.82	0.97	0.86
25		0.86	0.80	0.73	0.78	0.72	0.78	0.74	0.77	0.72
30		0.86	0.93	0.90	0.97	0.92	0.99	0.96	1.0	0.96
35		0.89	0.97	0.95	1.0	0.98	1.0	1.0		1.0
40		0.85	1.0	1.0		1.0				
45		1.0								

COMMENTS:

The thiophene chromatographic peak is strongly overlapped by methanol.

FIGURE 5.9.6: Ci/Co FOR AMBERLYST 15 MERCURY

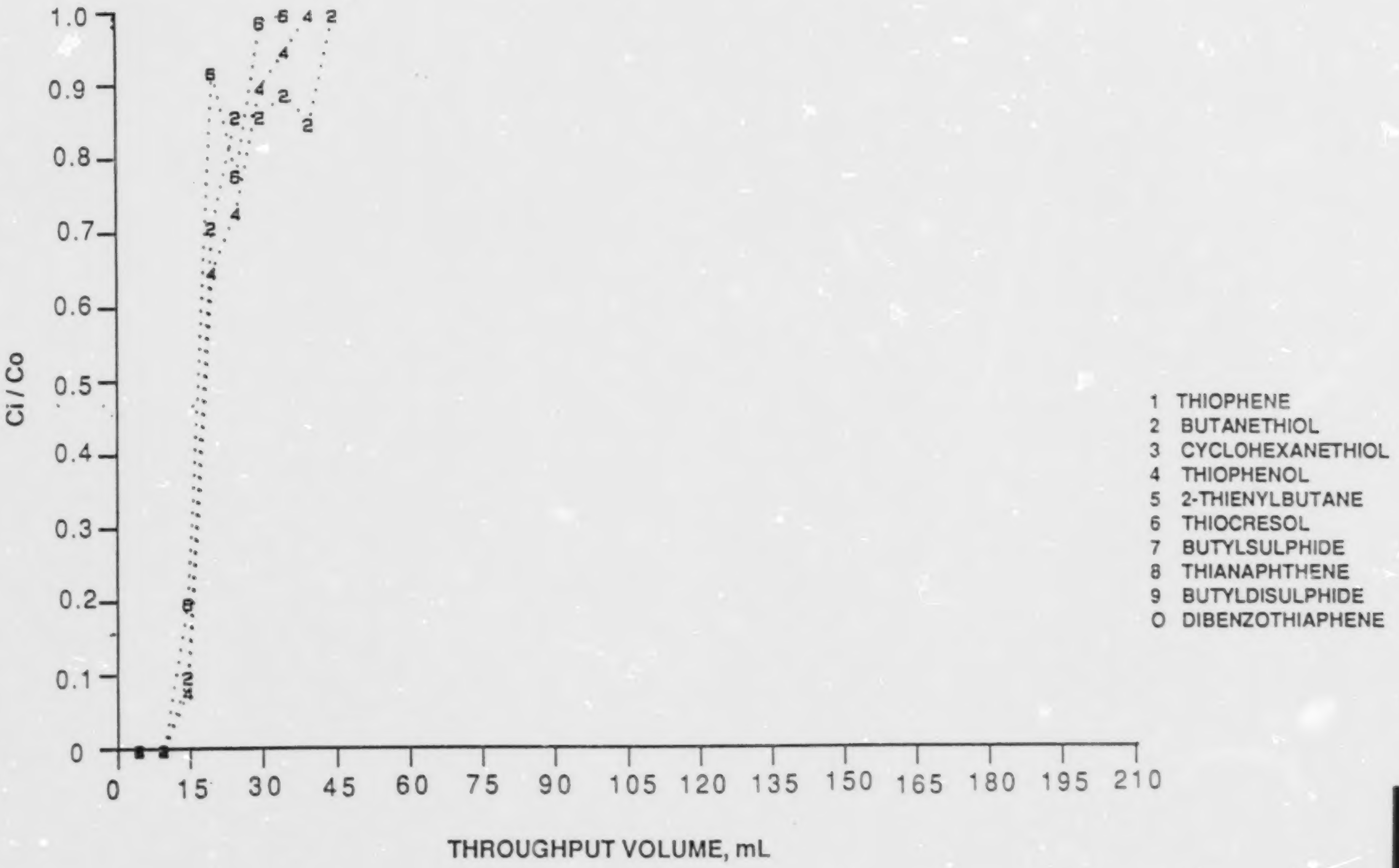

TABLE 5.9.7 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlyst 15 Nickel

Sorbent Weight: 7.41 g Column Bed Volume: 5.9 mL Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5		0.16	0	0	0	0	0	0	0	0
10		0.05	0	0	0	0	0	0	0	0
15		0.21	0.25	0.18	0.28	0.18	0.27	0.24	0.27	0.24
20		0.60	0.72	0.63	0.72	0.63	0.70	0.69	0.69	0.66
25		0.95	0.88	0.80	0.84	0.78	0.82	0.82	0.79	0.76
30		0.83	0.93	0.85	0.88	0.84	0.86	0.87	0.84	0.82
35		1.0	1.0	0.95	0.98	0.95	0.96	0.98	0.95	0.96
40				0.91	0.96	0.91	0.92	0.95	0.92	0.95
45				0.85	0.92	0.84	0.85	0.91	0.88	0.91
50				0.85	0.91	0.85	0.87	0.91	0.88	0.90

COMMENTS:

The thiophene chromatographic peak is strongly overlapped by methanol.

FIGURE 5. 9. 7: Ci/Co FOR AMBERLYST 15 NICKEL

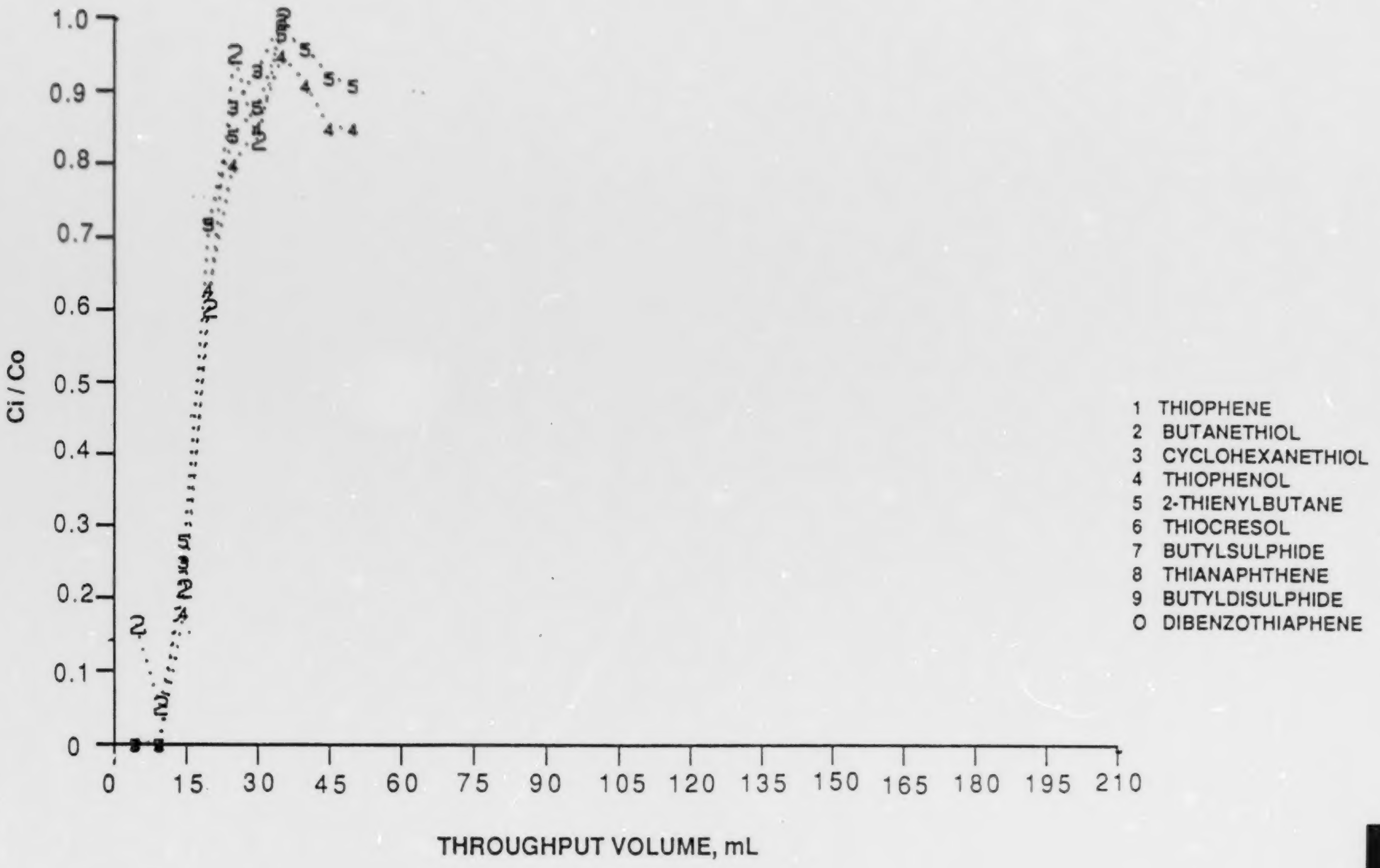

TABLE 5.9.8 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlyst 15 Strontium

Sorbent Weight: 7.60 g   Column Bed Volume: 6.2 mL   Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5		0.06	0	0	0	0	0	0	0	0
10		0.06	0	0	0.02	0	0.02	0.02	0.02	0.02
15		0.23	0.30	0.24	0.32	0.25	0.33	0.27	0.32	0.27
20		0.88	0.88	0.81	0.88	0.84	0.90	0.87	0.88	0.86
25		0.93	0.93	0.90	0.93	0.91	0.94	0.91	0.90	0.90
30		0.95	0.97	0.95	0.98	0.96	0.99	0.98	0.98	0.94
35		0.97	0.95	0.94	0.95	0.95	0.97	0.95	0.94	0.97
40		0.97	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
45		0.99								
50		0.98								
55		0.96								
60		0.97								
65		0.96								
70		0.96								
75		0.98								
80		1.0								

COMMENTS:

The thiophene chromatographic peak is strongly overlapped by methanol.

FIGURE 5.9.8: Ci/Co FOR AMBERLYST 15 STRONTIUM

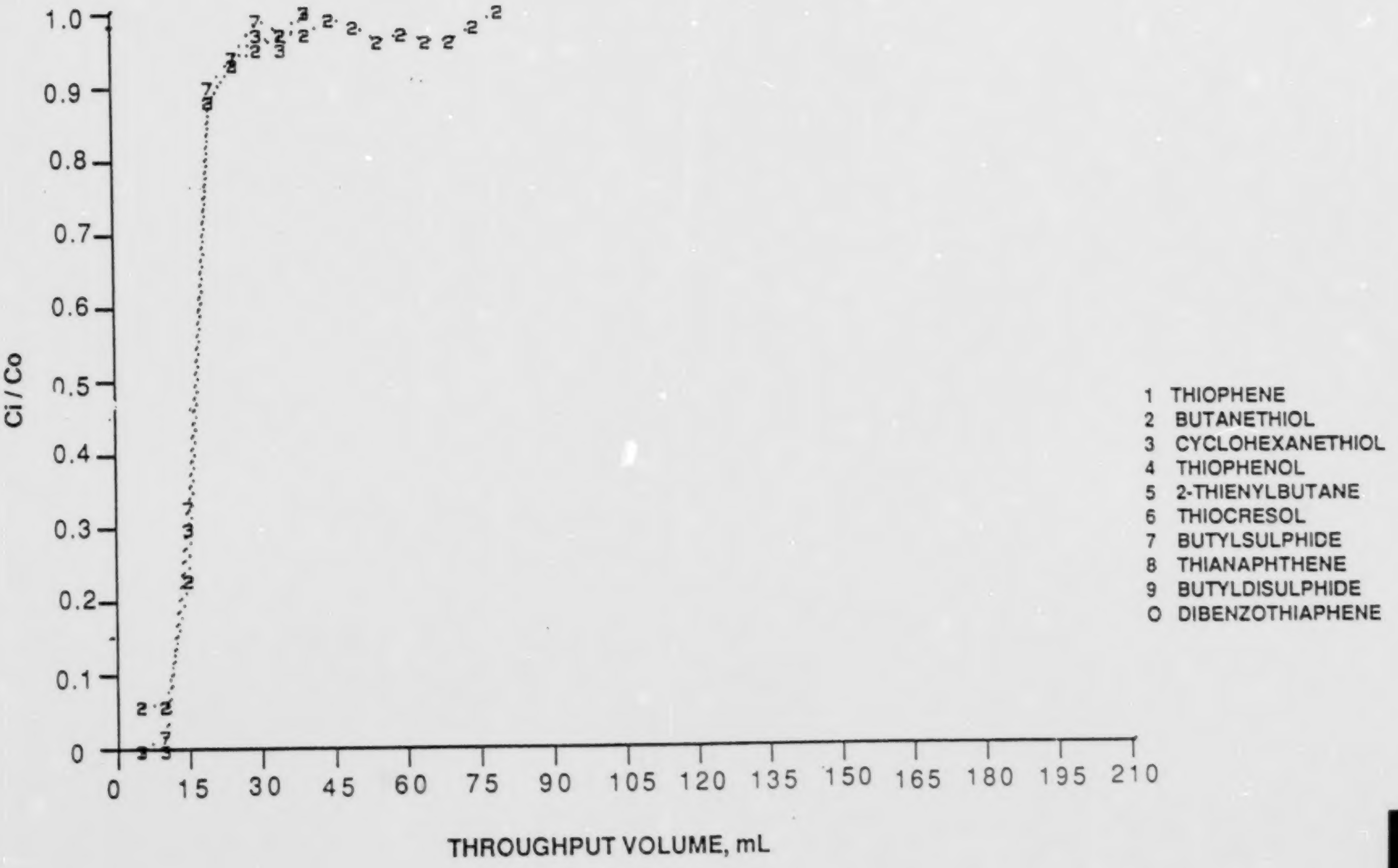

TABLE 5.9.9 C_i/C_o AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlyst 15 Titanium

Sorbent Weight: 7.11 g Column Bed Volume: 6.3 mL Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5		0.21	0	0	0	0	0	0	0	0
10		0.22	0	0	0	0	0	0	0	0
15		0.14	0.21	0.15	0.25	0.15	0.25	0.22	0.26	0.22
20		0.91	0.79	0.71	0.82	0.71	0.82	0.77	0.81	0.76
25		0.88	0.93	0.91	0.95	0.91	0.96	0.93	0.99	0.89
30		0.92	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
35		0.96								
40		1.0								

COMMENTS:

The thiophene chromatographic peak is strongly overlapped by methanol.

FIGURE 5.9.9: Ci/Co FOR AMBERLYST 15 TITANIUM

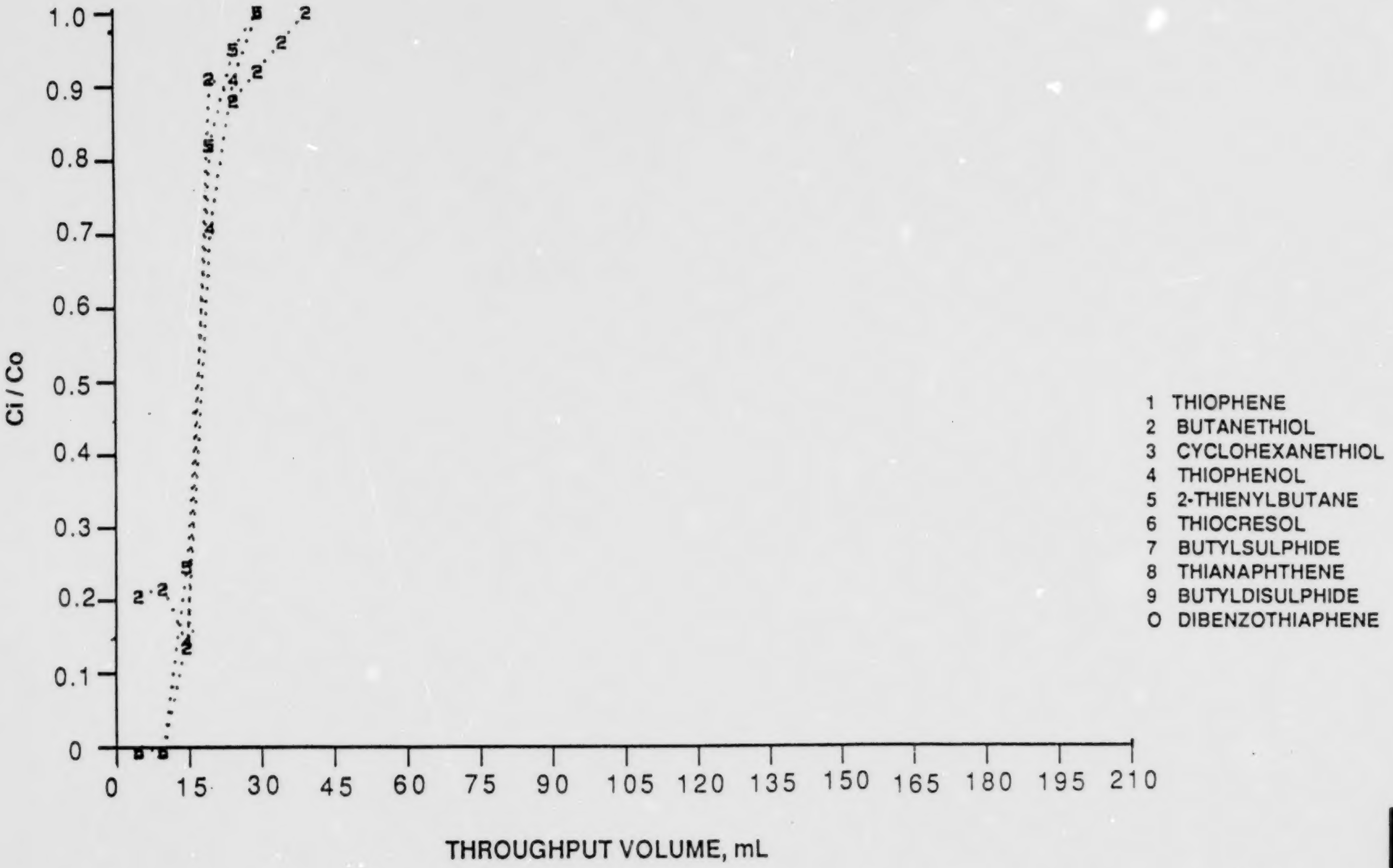

TABLE 5.9.10 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlyst 15 Vanadium (III)

Sorbent Weight: 6.89 g Column Bed Volume: 6.1 mL Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5		0.10	0	0.16	0	0	0	0	0	0
10		0.10	0	0.09	0	0	0	0	0	0
15		0.11	0.21	0.14	0.25	0.15	0.25	0.22	0.26	0.23
20		0.80	0.92	0.84	0.95	0.87	0.97	0.92	0.97	0.93
25		0.91	1.0	0.98	1.0	1.0	1.0	1.0	1.0	1.0
30		0.96		1.0						
35		1.0								

COMMENTS:

The thiophene chromatographic peak is strongly overlapped by methanol.

FIGURE 5.9.10: Ci/Co FOR AMBERLYST 15 VANADIUM (III)

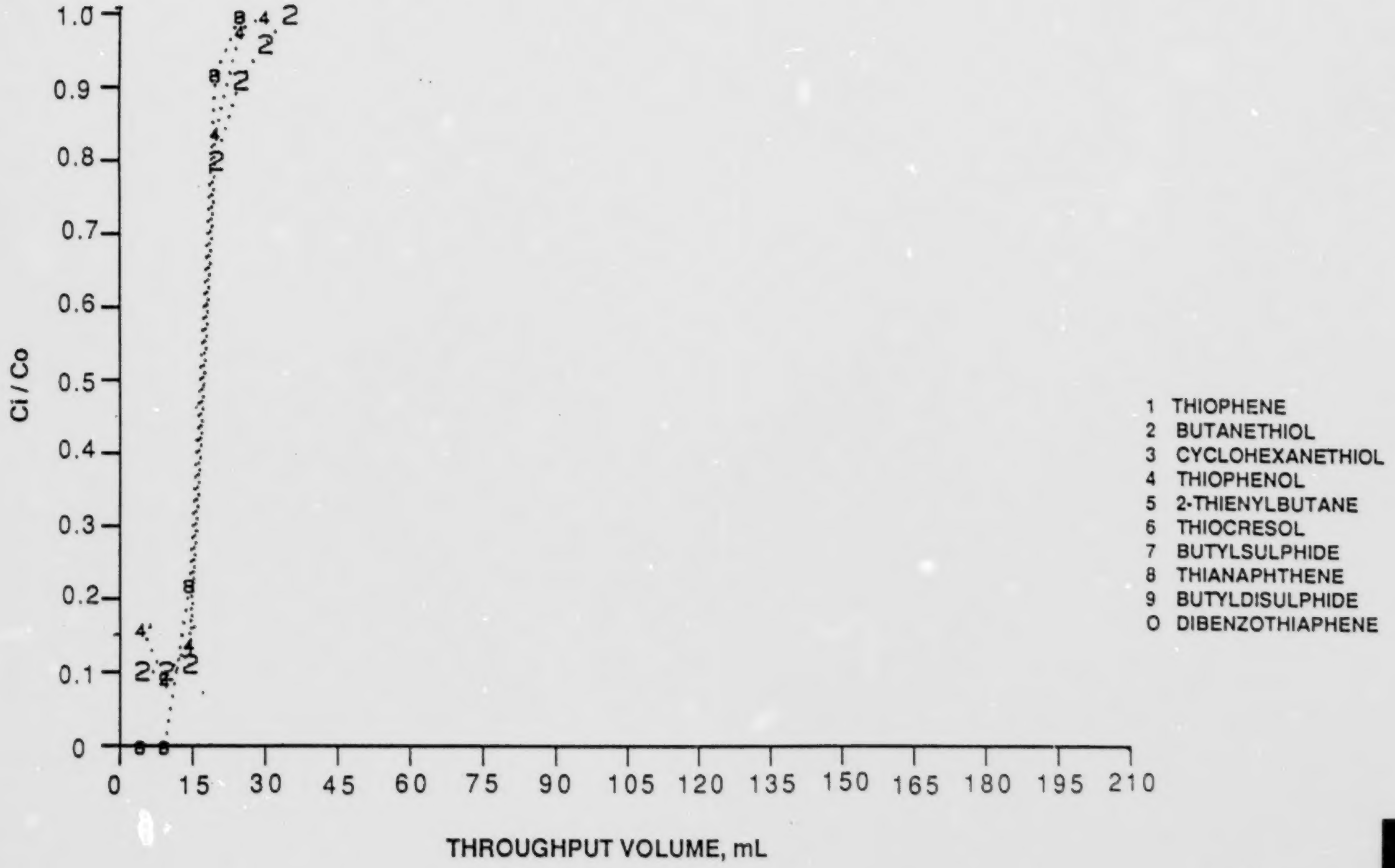

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TABLE 5.9.11 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Amberlyst 15 Zinc

Sorbent Weight: 7.62 g Column Bed Volume: 6 mL Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5		0	0	0	0	0	0	0	0	0
10		0	0	0	0.72	0	0.52	0.68	0.68	0.66
15		0	0	0	0.86	0	0.98	0.84	0.44	0.80
20		0	0	0	0.91	0	0.87	0.91	0.55	0.88
25		0	0	0	0.93	0	0.90	0.94	0.74	0.91
30		0.66	0.43	0	0.96	0	0.94	0.96	0.92	0.95
35		0.52	0.48	0	1.0	0	1.0	1.0	1.0	1.0
40		0.69	0.58	0.30		0.31				
45		0.83	0.73	0.53		0.56				
50		0.88	0.79	0.72		0.65				
55		0.95	0.86	0.76		0.69				
60		0.95	0.90	0.84		0.80				
65		0.98	0.97	0.93		0.94				
70		0.95	0.96	0.92		0.93				
75		0.94	0.90	0.81		1.0				

COMMENTS:

The thiophene chromatographic peak is strongly overlapped by methanol.

FIGURE 5.9.11: Ci/Co FOR AMBERLYST 15 ZINC

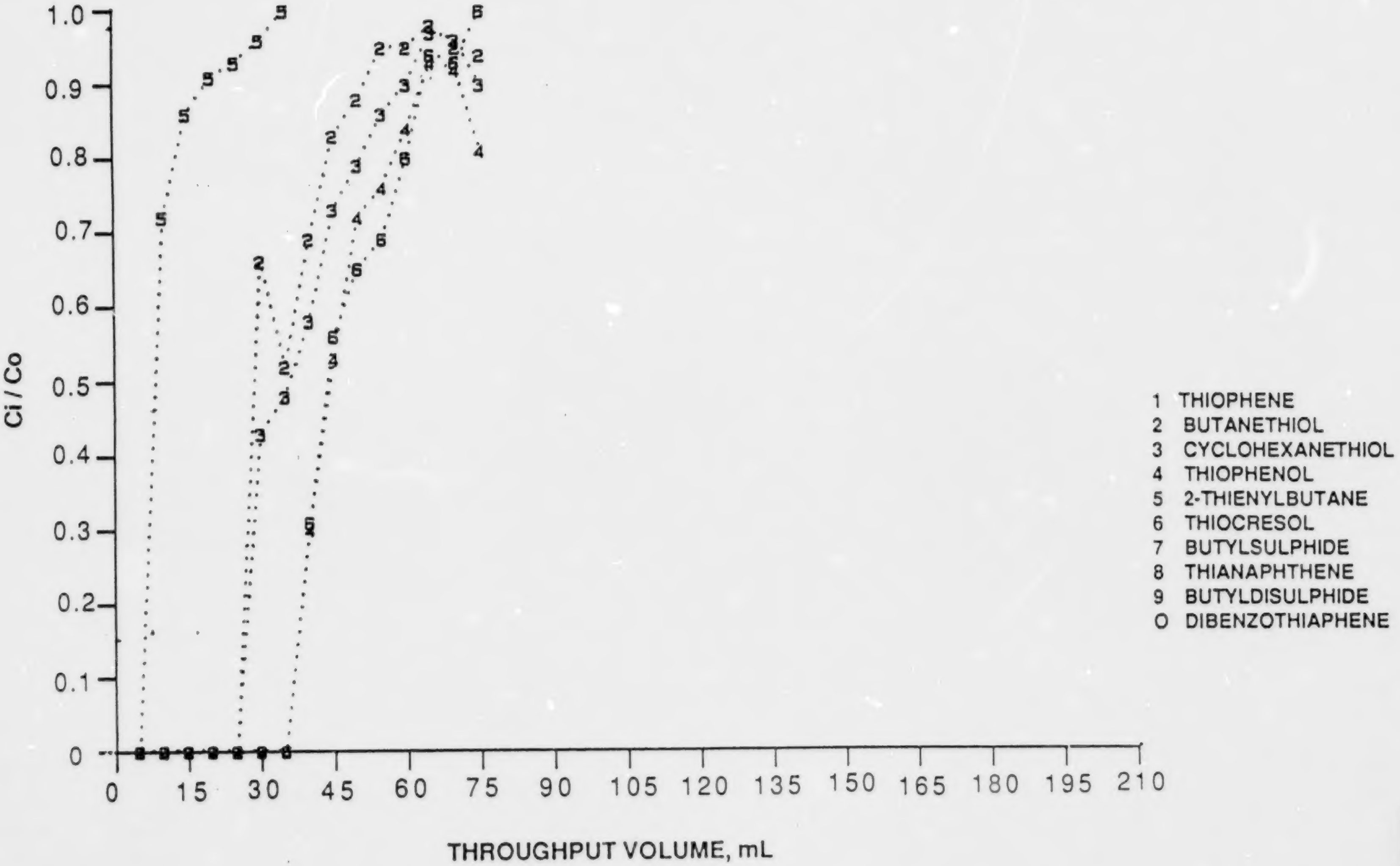

TABLE 5.10.1 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Attapulgite Copper

Sorbent Weight: 8.11 g   Column Bed Volume: 9.2 mL   Flowrate: 0.75 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.22	0.06	0	0	0	0	0	0	0	0
10	0.23	0.07	0	0.04	0	0	0	0	0	0
15	0.58	0.05	0	0.04	0.46	0	0	0.41	0.48	0.41
20	1.0	0.05	0	0.03	0.91	0	0.27	0.90	0.91	0.89
25		0.05	0	0	0.94	0	0.53	0.94	0.93	0.93
30		0.05	0	0	0.96	0	0.66	0.95	0.96	0.93
35		0.06	0	0	0.95	0	0.72	0.95	0.97	0.94
40		0.05	0	0	0.95	0	0.75	0.95	0.98	0.95
45		0.05	0	0	0.96	0	0.80	0.96	1.0	0.95
50		0.05	0	0	0.95	0	0.81	0.96		0.94
55		0.06	0	0.03	0.96	0	0.83	0.96		0.95
60		0.06	0	0.04	0.96	0	0.84	0.96		0.96
65		0.06	0	0.04	0.95	0	0.85	0.96		0.95
70		0.05	0	0.04	0.96	0	0.86	0.96		0.96
75		0.06	0	0.04	0.95	0	0.86	0.95		0.95
80		0.05	0	0.03	0.95	0	0.89	0.95		0.95
85		0.06	0	0.03	0.96	0	0.89	0.95		0.95
90		0.06	0	0.03	0.92	0	0.89	0.94		0.94
95		0.06	0	0.04	0.98	0	0.96	0.96		0.96
100		0.06	0	0.04	0.98	0	0.96	0.96		0.96
105		0.06	0	0.03	0.94	0	0.92	0.96		0.96

COMMENTS:

Results stay same to end 46 total samples 230 mL.

FIGURE 5.10.1: Ci/Co FOR ATTAPULGITE COPPER

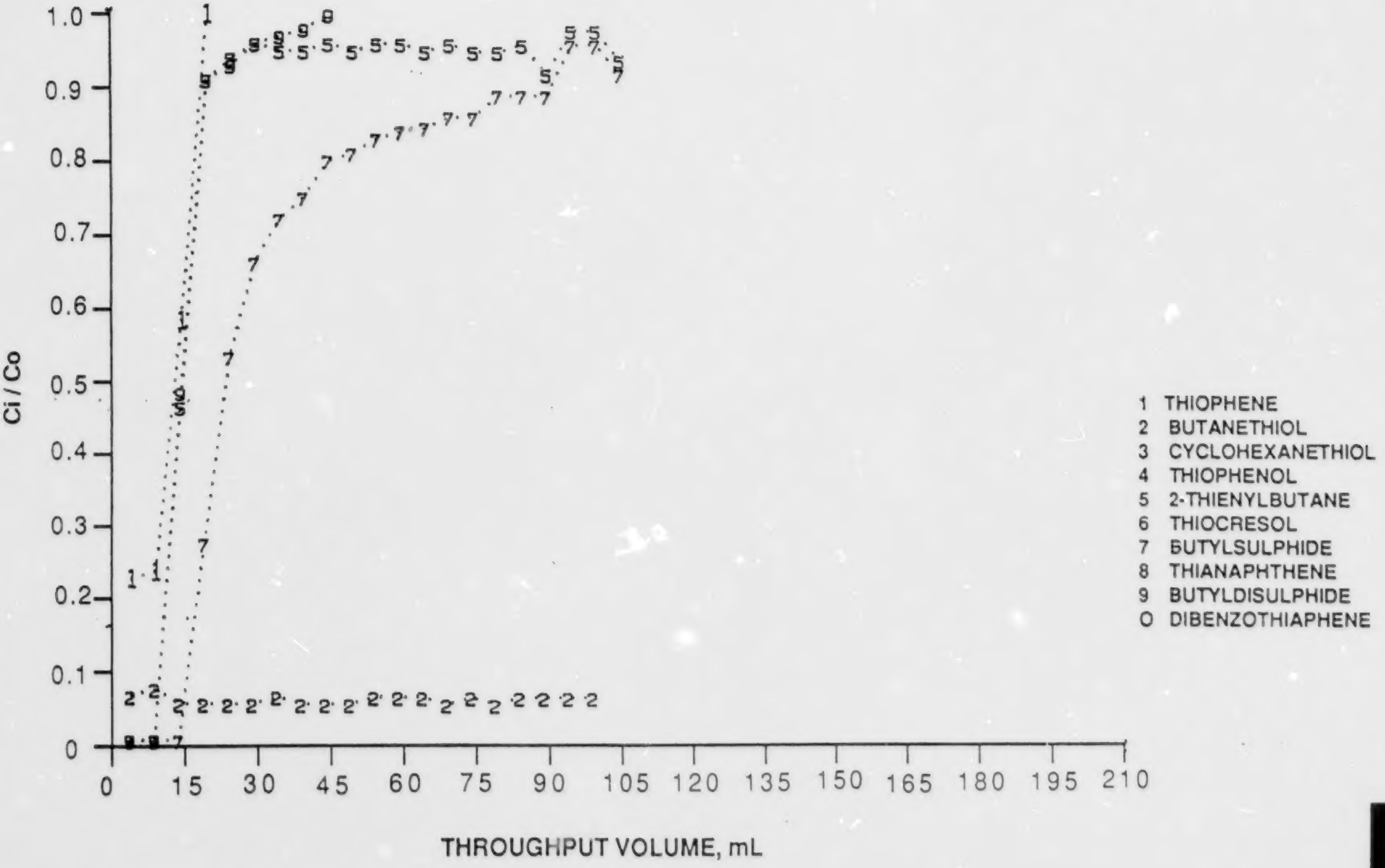

TABLE 5.10.2 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Attapulgite Iron (III)

Sorbent Weight: 7.42 g Column Bed Volume: 8.8 mL Flowrate: 0.75 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.25	0.09		0.04	0.03		0.02	0.02		0.02
10	0.53	0.15	0.23		0.34		0.34	0.35	0.37	0.35
15	1.0	0.71	0.69	0.12	0.79	0.04	0.82	0.82	0.80	0.81
20		0.9	0.85	0.26	0.91	0.12	0.92	0.91	0.89	0.87
25		0.92	0.88	0.37	0.92	0.19	0.93	0.93	0.91	0.89
30		0.94	0.88	0.46	0.92	0.25	0.93	0.92	0.91	0.90
35		0.97	0.90	0.52	0.93	0.32	0.94	0.93	0.91	0.90
40		0.92	0.87	0.54	0.90	0.35	0.91	0.91	0.89	0.89
45		0.92	0.87	0.54	0.90	0.35	0.91	0.91	0.90	0.89
50		0.91	0.87	0.57	0.90	0.39	0.91	0.91	0.90	0.90
55		0.90	0.89	0.62	0.92	0.43	0.93	0.93	0.92	0.92
60		0.93	0.90	0.64	0.93	0.44	0.94	0.94	0.92	0.92
65		0.92	0.90	0.65	0.92	0.46	0.93	0.93	0.92	0.91
70		0.90	0.89	0.66	0.92	0.48	0.93	0.93	0.92	0.92
75		0.94	0.91	0.68	0.93	0.51	0.94	0.93	0.92	0.91
80		0.93	0.90	0.68	0.92	0.51	0.93	0.93	0.92	0.91
85		0.97	0.93	0.70	0.94	0.52	0.95	0.94	0.93	0.93
90		0.97	0.93	0.71	0.94	0.54	0.95	0.94	0.93	0.92
95		1.0	0.95	0.72	0.95	0.55	0.95	0.94	0.93	0.91
100			0.94	0.72	0.94	0.55	0.95	0.95	0.94	0.92
105			0.95	0.73	0.95	0.56	0.96	0.95	0.94	0.93
110			0.93	0.71	0.93	0.55	0.94	0.93	0.92	0.91
115			0.96	0.74	0.96	0.57	0.96	0.95	0.93	0.92
120			0.96	0.76	0.95	0.57	0.96	0.95	0.94	0.93
125			0.89	0.69	0.91	0.55	0.92	0.92	0.91	0.91

FIGURE 5.10.2: Ci/Co FOR ATTAPULGITE IRON (III)

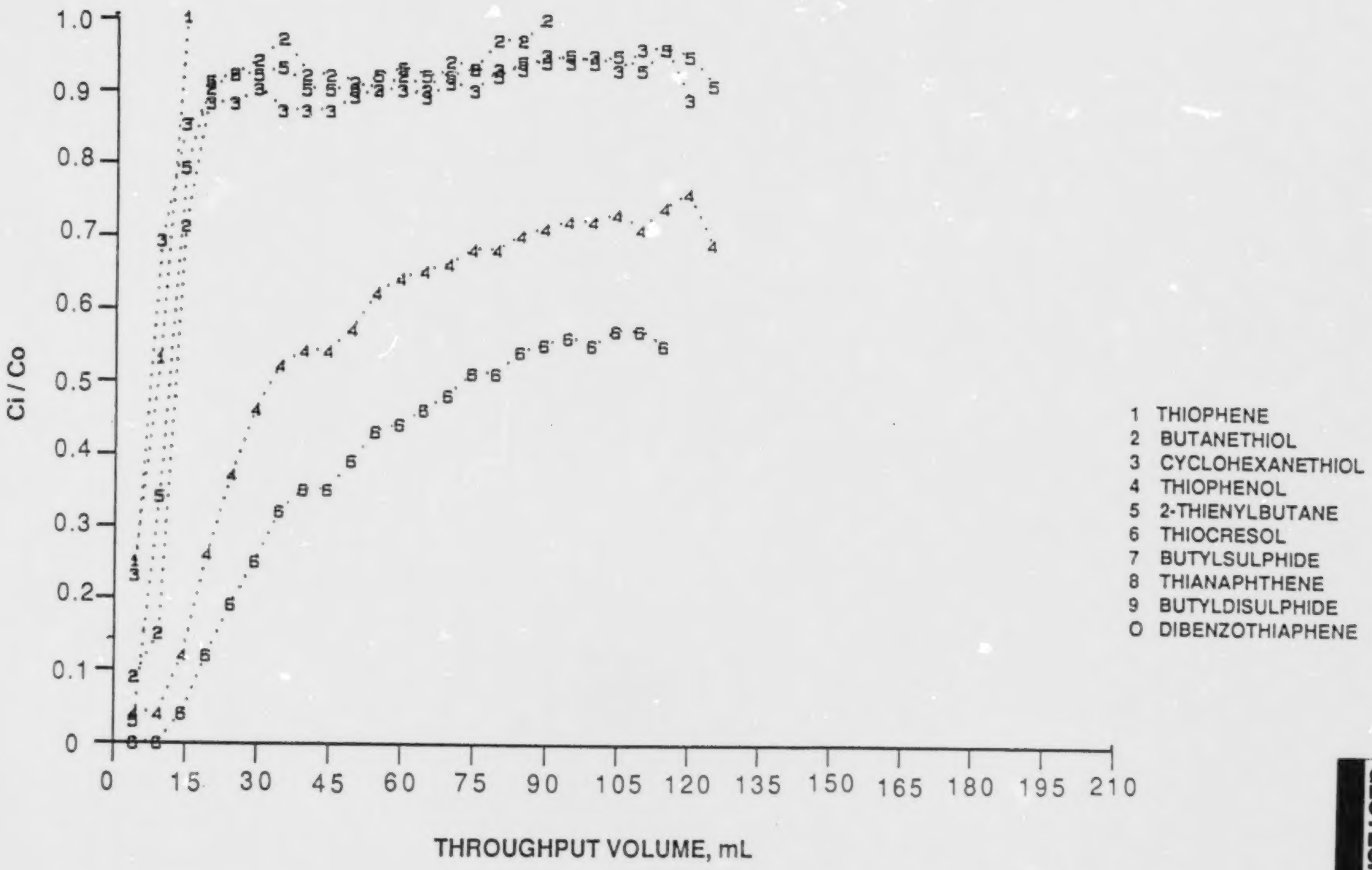

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TABLE 5.10.3 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Attapulgite Mercury

Sorbent Weight: 8.24 g Column Bed Volume: 9.4 mL Flowrate: 0.75 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.25	0.06	0	0.06	0	0	0.03	0	0	0.02
10	0.26	0.31	0	0.06	0.02	0	0.02	0	0	0.01
15	0.63	0.06	0	0	0.42	0	0.17	0.37	0.19	0.37
20	1.0	0.07	0	0	0.94	0	0.56	0.92	0.69	0.92
25		0.23	0	0.03	0.93	0	0.94	0.92	0.92	0.91
30		0.48	0.29	0.03	0.92	0	0.91	0.91	0.91	0.91
35		0.72	0.29	0.24	0.95	0	0.94	0.94	0.94	0.92
40		0.64	0.29	0.32	0.95	0	0.94	0.94	0.94	0.93
45		0.78	0.49	0.40	0.94	0	0.94	0.94	0.93	0.92
50		0.81	0.65	0.55	0.91	0.24	0.92	0.92	0.92	0.93
55		0.87	0.73	0.60	0.92	0.39	0.93	0.93	0.93	0.93
60		0.93	0.81	0.65	0.9[illegible]	0.54	0.95	0.95	0.95	0.95
65		1.0	0.90	0.69	0.96	0.62	0.96	0.96	0.96	0.96
70			0.90	0.71	0.95	0.64	0.96	0.96	0.96	0.96
75			0.89	0.73	0.94	0.66	0.94	0.94	0.94	0.94
80			0.88	0.74	0.94	0.69	0.93	0.93	0.93	0.93
85			0.89	0.76	0.94	0.70	0.93	0.94	0.94	0.93
90			0.90	0.79	0.95	0.72	0.94	0.94	0.94	0.94
95			0.91	0.82	0.96	0.74	0.95	0.95	0.94	0.93
100			0.91	0.78	0.94	0.74	0.93	0.93	0.92	0.93
105			0.85	0.73	0.91	0.70	0.90	0.91	0.91	0.91

FIGURE 5.10.3: Ci/Co FOR ATTAPULGITE MERCURY

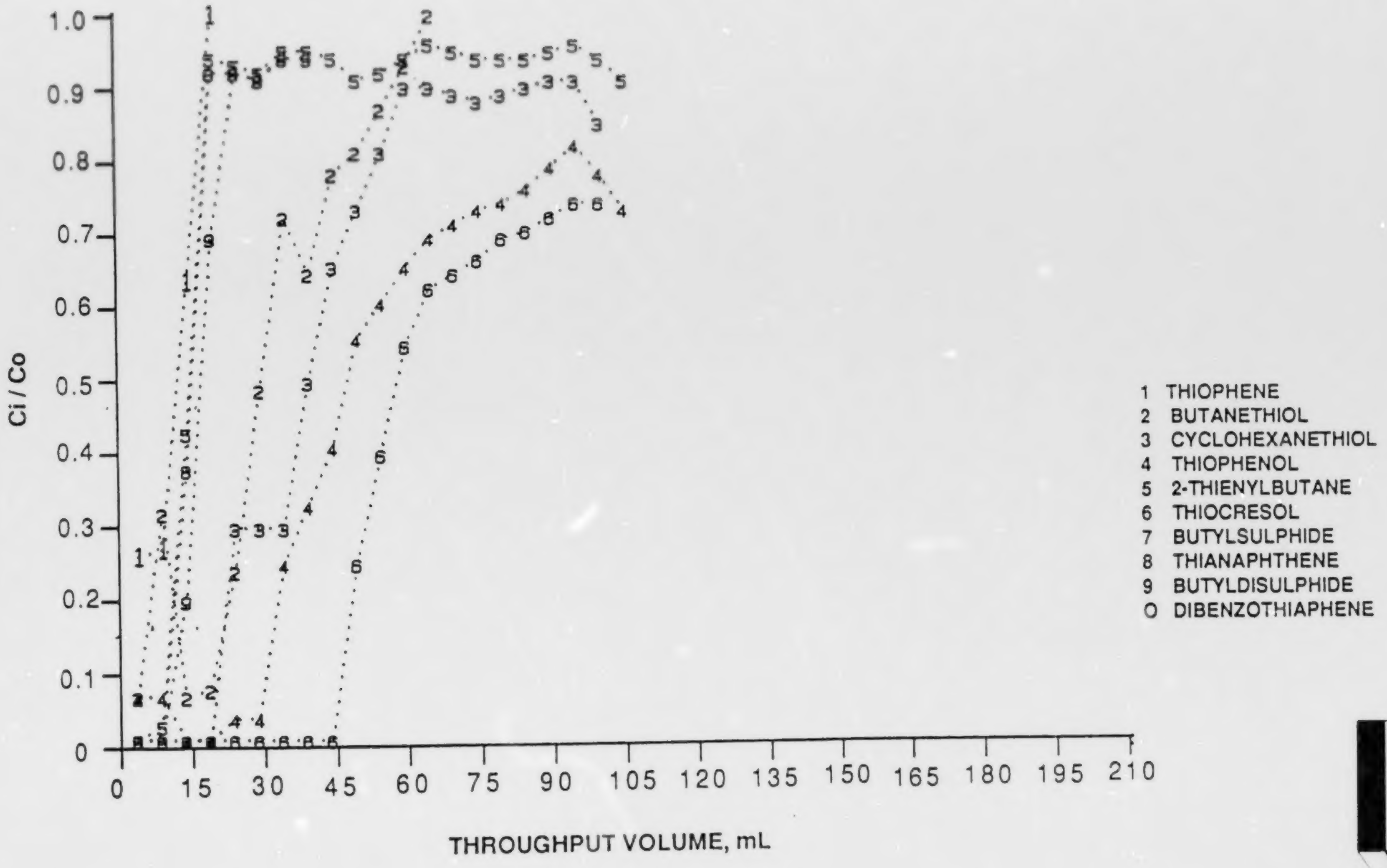


TABLE 5.10.4 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Attapulgite Nickel

Sorbent Weight: 6.69 g Column Bed Volume: 8.9 mL Flowrate: 0.75 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.22	0.26	0	0	0	0	0	0	0	0
10	0.23	0.27	0	0	0	0	0	0	0	0
15	0.54	0.36	0.38	0.16	0.46	0.12	0.42	0.42	0.45	0.39
20	0.61	0.82	1.0	0.59	1.0	0.52	1.0	1.0	1.0	1.0
25	0.76	0.92		0.73		0.65				
30	0.96	1.0		0.75		0.68				
35	0.96			0.78		0.70				
40	0.96			0.89		0.81				
45	0.94			0.84		0.76				
50	0.98			0.82		0.75				
55	0.96			0.87		0.80				
60	1.0			0.96		0.89				
65				0.95		0.96				
70				0.90		0.82				
75				0.88		0.81				
80				0.91		0.84				
85				0.90		0.83				
90				0.90		0.83				
95				0.93		0.86				
100				1.0		0.90				
105						0.95				
110						1.0				

FIGURE 5.10.4: Ci/Co FOR ATTAPULGITE NICKEL

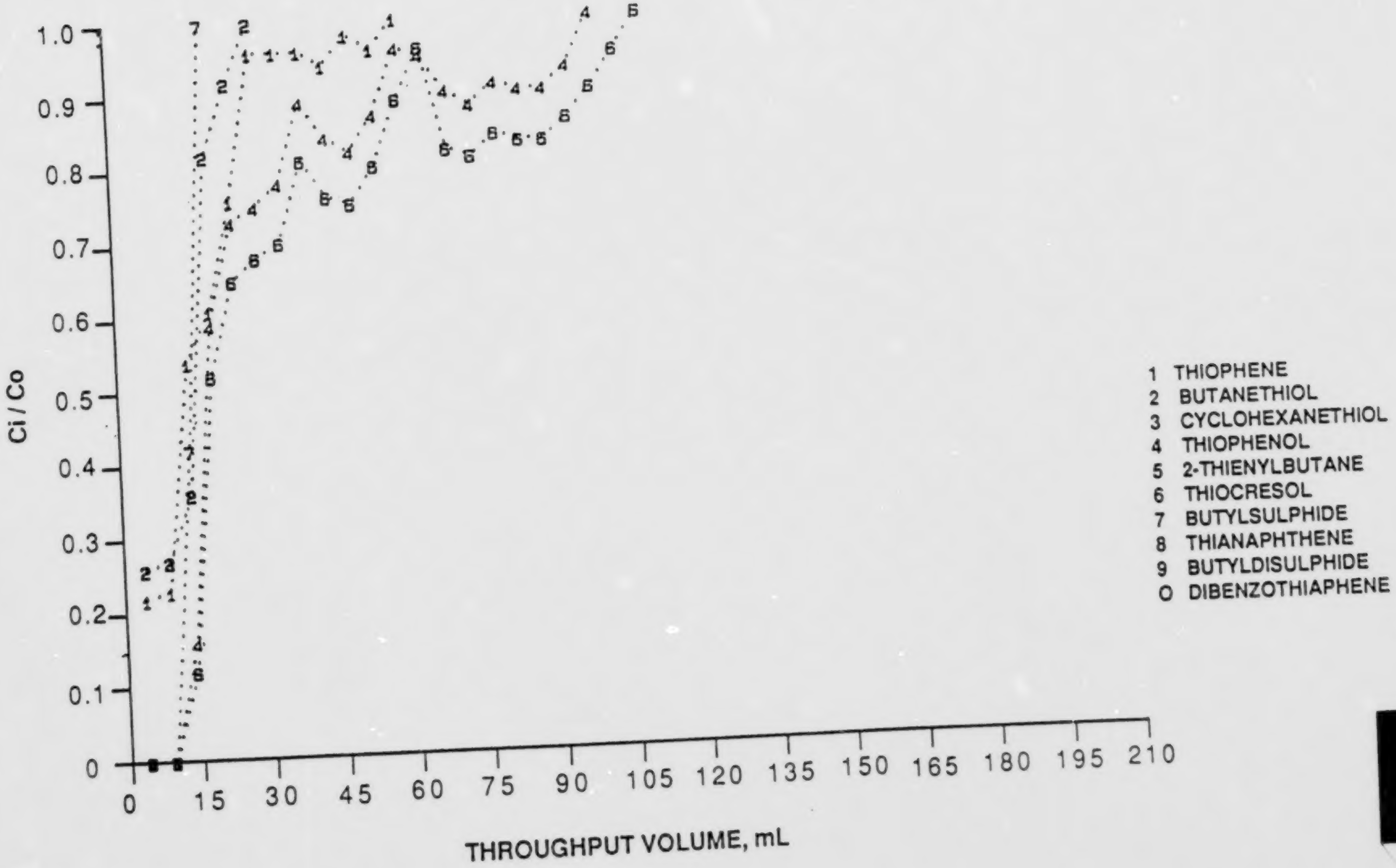


TABLE 5.10.5 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Attapulgite Zinc

Sorbent Weight: 8.47 g Column Bed Volume: 8.3 mL Flowrate: 0.75 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.34	0.07	0	0.05	0	0	0	0	0	0
10	0.34	0.06	0	0.05	0.03	0	0	0	0	0.02
15	0.78	0.09	0.09	0.04	0.67	0	0.60	0.62	0.67	0.68
20	0.90	0.68	0.86	0.05	0.93	0.05	0.93	0.93	0.94	0.97
25	0.91	0.86	0.96	0.49	1.0	0.51	1.0	1.0	1.0	1.0
30	0.94	0.89	0.95	0.74		0.67				
35	0.95	0.91	0.96	0.82		0.75				
40	0.95	0.93	0.99	0.87		0.80				
45	0.98	0.95	0.99	0.89		0.83				
50	0.97	0.96	1.0	0.90		0.85				
55	0.98	0.99		0.92		0.87				
60	0.94	0.96		0.94		0.89				
65	0.90	0.92		0.91		0.87				
70	0.93	0.94		0.93		0.89				
75	0.96	0.96		0.92		0.88				
80	0.95	0.95		0.92		0.89				
85	0.97	0.98		0.93		0.90				
90	0.97	0.97		0.93		0.90				

FIGURE 5.10.5: Ci/Co FOR ATTAPULGITE ZINC

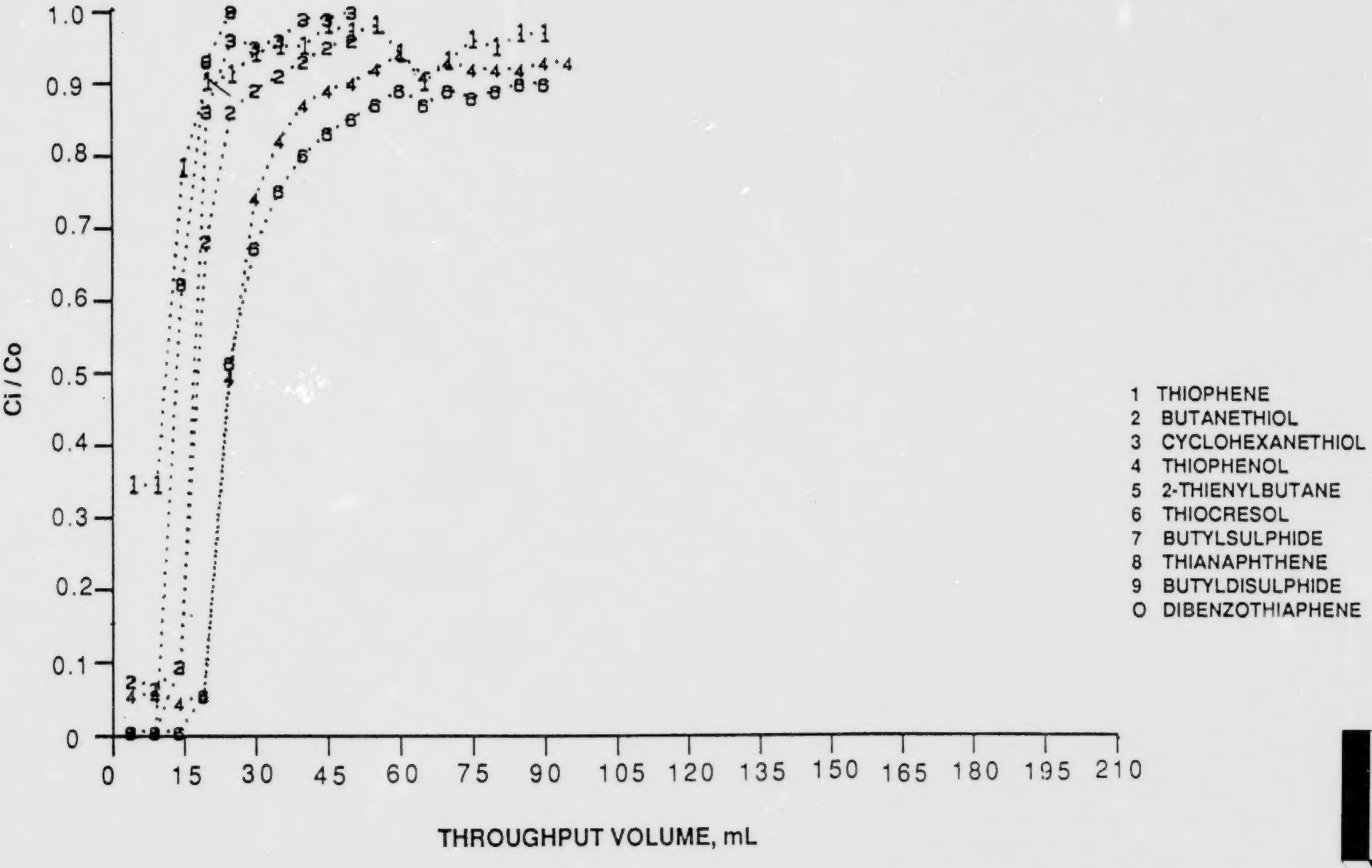


TABLE 5.11.1 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Attapulgite Chlorhydrol

Sorbent Weight: 6.92 g   Column Bed Volume: 5.2 mL   Flowrate: 0.42 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.21	0.26	0	0	0	0	0	0	0	
10	0.21	0.26	0	0	0	0	0	0	0	
15	0.42	0.11	0.22	0	0.32	0	0.28	0	0	
20	0.84	0.59	0.76	0.12	0.85	0.09	0.82	0.83	0.84	
25	0.94	0.86	0.91	0.26	0.96	0.23	0.95	0.96	0.96	
30	0.96	0.90	0.96	0.37	1.0	0.32	0.98	0.98	0.98	
35	0.94	0.89	0.94	0.42		0.36	0.97	0.98	0.98	
40	0.96	0.93	0.97	0.45		0.39	0.99	1.0	0.99	
45	0.96	0.92	0.96	0.47		0.41	1.0		1.0	
50	0.95	0.91	0.96	0.49		0.43				
55	0.92	0.90	0.96	0.50		0.45				
60	0.93	0.92	0.97	0.52		0.47				
65	0.93	0.93	0.98	0.54		0.50				
70	0.96	0.96	0.98	0.56		0.52				
75	0.96	0.96	1.0	0.58		0.54				
80	0.97	0.95		0.60		0.55				
85	0.96	0.95		0.61		0.56				
90	0.97	0.96		0.62		0.58				
95	0.96	0.96		0.63		0.58				
100	1.0	1.0		0.65		0.59				
105				0.65		0.59				
110				0.66		0.60				
115				0.67		0.62				
120				0.67		0.62				
125				0.69		0.63				

FIGURE 5.11.1: Ci/Co FOR ATTAPULGITE CHLORHYDROL

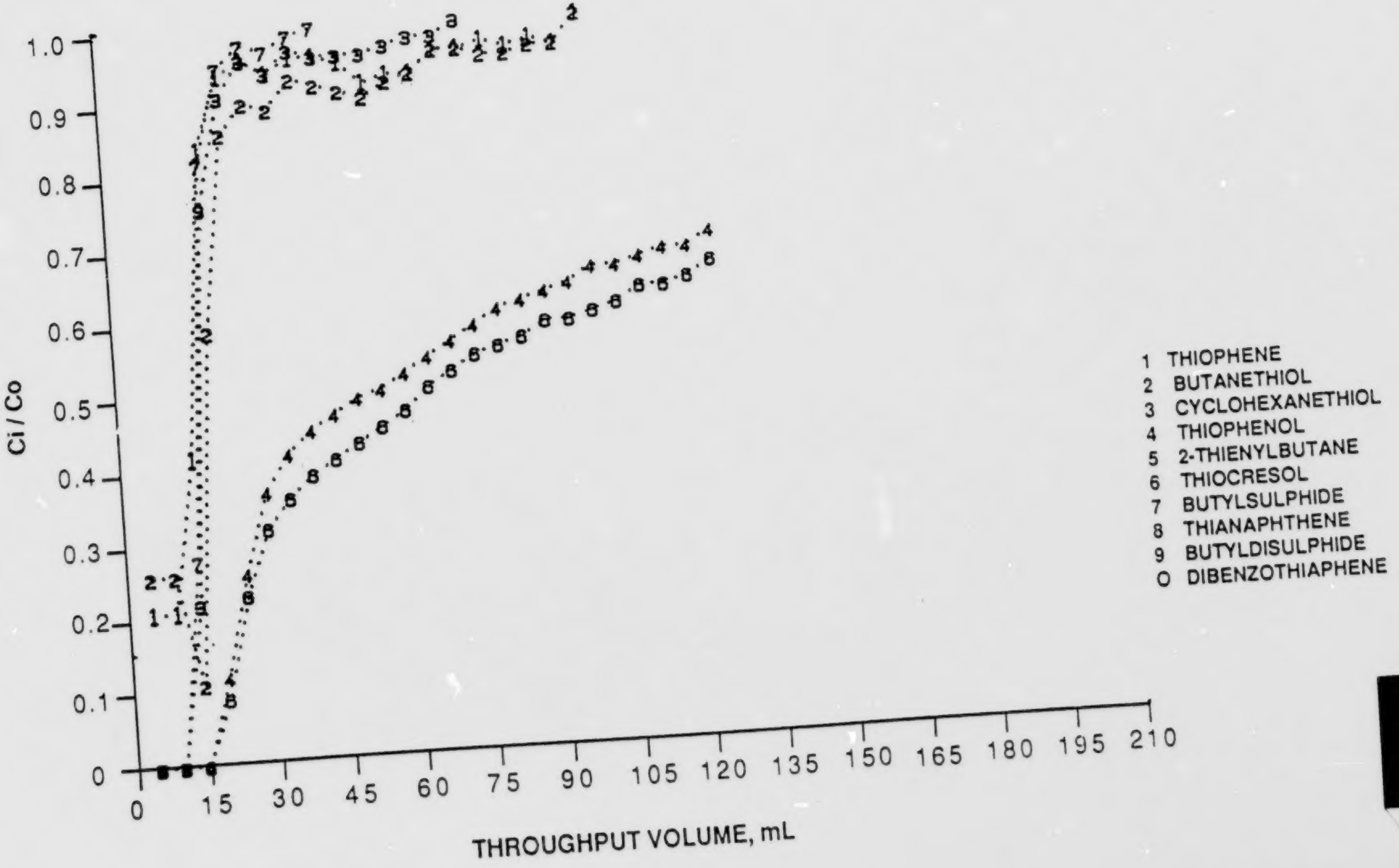


TABLE 5.11.2 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Attapulgite Chlorhydrol Copper

Sorbent Weight: 7.86 g Column Bed Volume: 9.3 mL Flowrate: 0.75 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.31	0.06	0	0.05	0	0	0.04	0	0	0
10	0.33	0.06	0	0.05	0.04	0	0.03	0.03	0	0.03
15	0.58	0.06	0	0.05	0.52	0	0.05	0.49	0.52	0.52
20	0.77	0.06	0	0.04	0.86	0	0.23	0.85	0.82	0.91
25	0.80	0.07	0	0.04	0.91	0	0.42	0.92	0.92	0.99
30	0.77	0.06	0	0.04	0.90	0	0.55	0.91	0.94	0.99
35	0.80	0.06	0	0.04	0.92	0	0.67	0.93	0.97	1.0
40	0.81	0.06	0	0.04	0.93	0	0.74	0.94	1.0	
45	[illegible]	0.19	0	0.04	0.96	0	0.83	0.97		
50	[illegible]	0.06	0	0.04	0.95	0	0.85	0.96		
55	0.80	0.06	0	0.04	0.92	0	0.85	0.94		
60	0.87	0.06	0	0.04	0.95	0	0.89	0.95		
65	0.91	0.18	0	0.05	0.95	0	0.90	0.96		
70	0.90	0.17	0	0.05	0.93	0	0.90	0.94		
75	0.91	0.17	0	0.05	0.98	0	0.96	0.95		
80	0.92	0.17	0	0.05	0.99	0	0.98	0.94		
85	0.92	0.18	0	0.05	0.99	0	0.99	0.96		
90	0.92	0.17	0	0.05	0.99	0	1.0	0.96		
95	0.92	0.17	0	0.05	1.0	0		0.91		
100	0.92	0.17	0	0.05		0		0.95		
105	0.92	0.17	0	0.05		0		0.97		
110	0.93	0.17	0	0.05		0		0.95		
115	0.95	0.18	0	0.06		0		0.96		
120	0.96	0.18	0	0.05		0		0.95		
125	0.94	0.17	0	0.05		0		0.96		

TABLE 5.11.2 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Attapulgite Chlorhydrol Copper

Sorbent Weight: 7.86 g   Column Bed Volume: 9.3 mL   Flowrate: 0.75 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
130	0.95	0.18	0	0.05		0		0.96		
135	0.95	0.18	0	0.06		0		0.89		
140	0.92	0.16	0	0.05		0		0.94		
145	0.93	0.17	0	0.05		0		0.94		
150	0.94	0.17	0	0.05		0		0.93		
155	0.94	0.17	0	0.05		0		0.94		
160	0.94	0.17	0	0.05		0		0.86		
165	0.96	0.18	0	0.05		0		0.94		
170	0.98	0.17	0	0.05		0		0.93		
175	1.0	0.18	0	0.05		0		0.96		
180										
185										
190										
195										
200										
205		0.18	0	0.04				0.95		
210		0.09	0	0.03				0.94		
215		0.09	0	0.04				0.94		

FIGURE 5.11.2: Ci/Co FOR ATTAPULGITE CHLORHYDROL COPPER

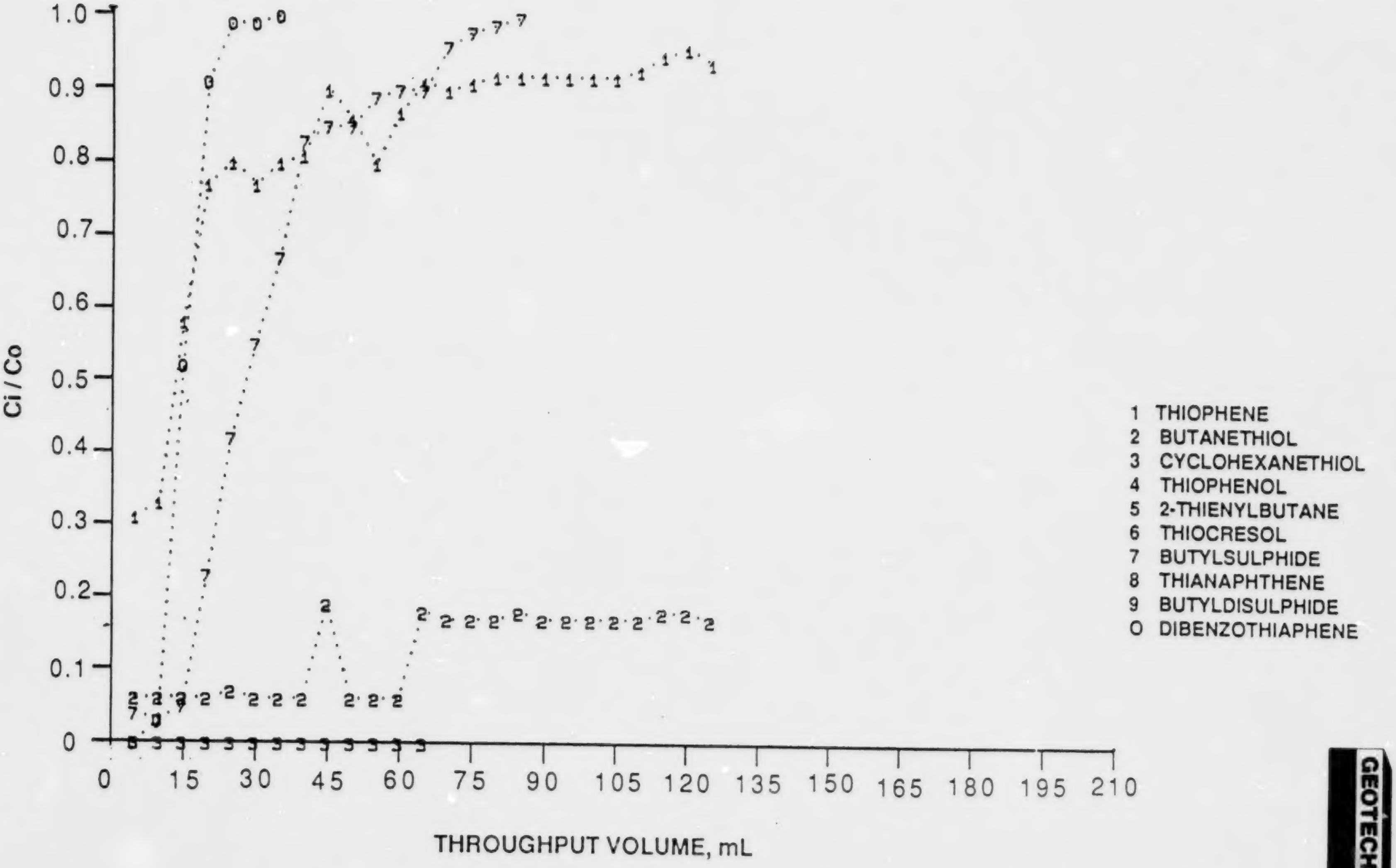


TABLE 5.11.3 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Attapulgite Chlorhydrol Iron (III)

Sorbent Weight: 7.20 g   Column Bed Volume: 8.7 mL   Flowrate: 0.75 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.24	0.32	0	0	0	0	0	0	0	0
10	0.25	0.32	0	0	0	0	0	0	0	0
15	0.59	0.15	0.25	0	0.40	0	0.37	0.39	0.43	0.38
20	0.99	0.68	0.64	0	0.82	0	0.83	0.83	0.83	0.81
25	1.0	0.81	0.77	0.10	0.91	0.04	0.91	0.91	0.91	0.89
30		0.83	0.78	0.17	0.91	0.09	0.91	0.91	0.91	0.90
35		0.85	0.80	0.30	0.92	0.14	0.92	0.92	0.92	0.91
40		1.0	0.84	0.38	0.93	0.18	0.94	0.94	0.93	0.91
45			0.86	0.44	0.94	0.24	0.94	0.93	0.93	0.91
50			0.86	0.49	0.93	0.29	0.93	0.93	0.92	0.91
55			0.89	0.54	0.95	0.33	0.95	0.95	0.94	0.93
60			0.88	0.55	0.95	0.34	0.95	0.94	0.93	0.93
65			0.87	0.56	0.94	0.35	0.95	0.94	0.92	0.94
70			0.87	0.57	0.94	0.36	0.94	0.93	0.93	0.92
75				0.58	0.94	0.37	0.95	0.93	0.92	0.93
80				0.58	0.92	0.38	0.94	0.93	0.93	0.92
85				0.59	0.91	0.39	0.93	0.93	0.93	0.91
90				0.60		0.40	0.92	0.92	0.92	0.91
95				0.60		0.41	0.93	0.93	0.92	0.92
100				0.60		0.41	0.92	0.92	0.91	0.91
105				0.60		0.42	0.92	0.92	0.91	0.91
110				0.61		0.43	0.92	0.92	0.91	0.91
115				0.61		0.43				
120				0.61		0.42				
125				0.61		0.43				
130				0.62		0.42				
135				0.62						
140				0.63						
145				0.62						
150				0.63						
155										
160										
165										

FIGURE 5. 11. 3: Ci/Co FOR ATTAPULGITE CHLORHYDROL IRON (III)

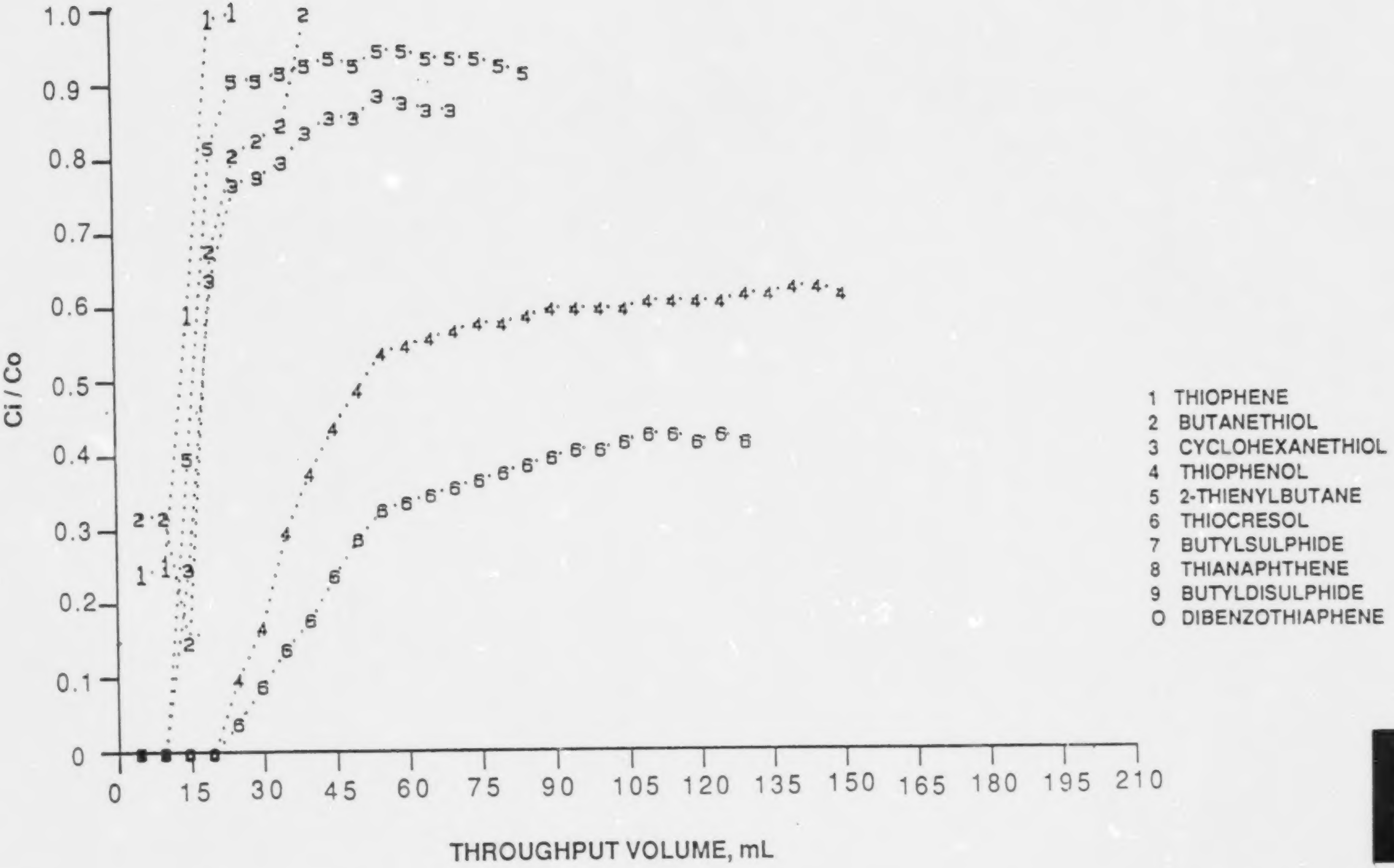


TABLE 5.11.4 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Attapulgite Chlorhydrol Mercury

Sorbent Weight: 7.12 g Column Bed Volume: 9.4 mL Flowrate: 0.75 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.22	0.27	0	0	0	0	0	0	0	0
10	0.23	0.27	0	0	0	0	0	0	0	0
15	0.55	0.36	0.37	0.20	0.47	0.15	0.41	0.42	0.46	0.42
20	0.93	0.90	0.88	0.55	0.92	0.48	0.90	0.90	0.92	0.91
25	0.98	0.96	0.95	0.68	0.97	0.64	0.96	0.97	0.97	0.96
30	0.97	0.97	1.0	0.78	1.0	0.75	1.0	1.0	1.0	1.0
35	1.0	1.0		0.80		0.76				
40				0.81		0.78				
45				0.82		0.80				
50				0.84		0.81				
55				0.85		0.82				
60				0.86		0.82				
65				0.84		0.82				
70				0.86		0.83				
75				0.87		0.85				
80				0.87		0.85				
85				0.87		0.85				
90				0.87		0.85				
95				0.89		0.86				
100				0.89		0.86				
105				0.88		0.85				
110				0.88		0.86				
115				0.89		0.86				
120				0.90		0.87				
125				0.90		0.87				

FIGURE 5.11.4: Ci/Co FOR ATTAPULGITE CHLORHYDROL MERCURY

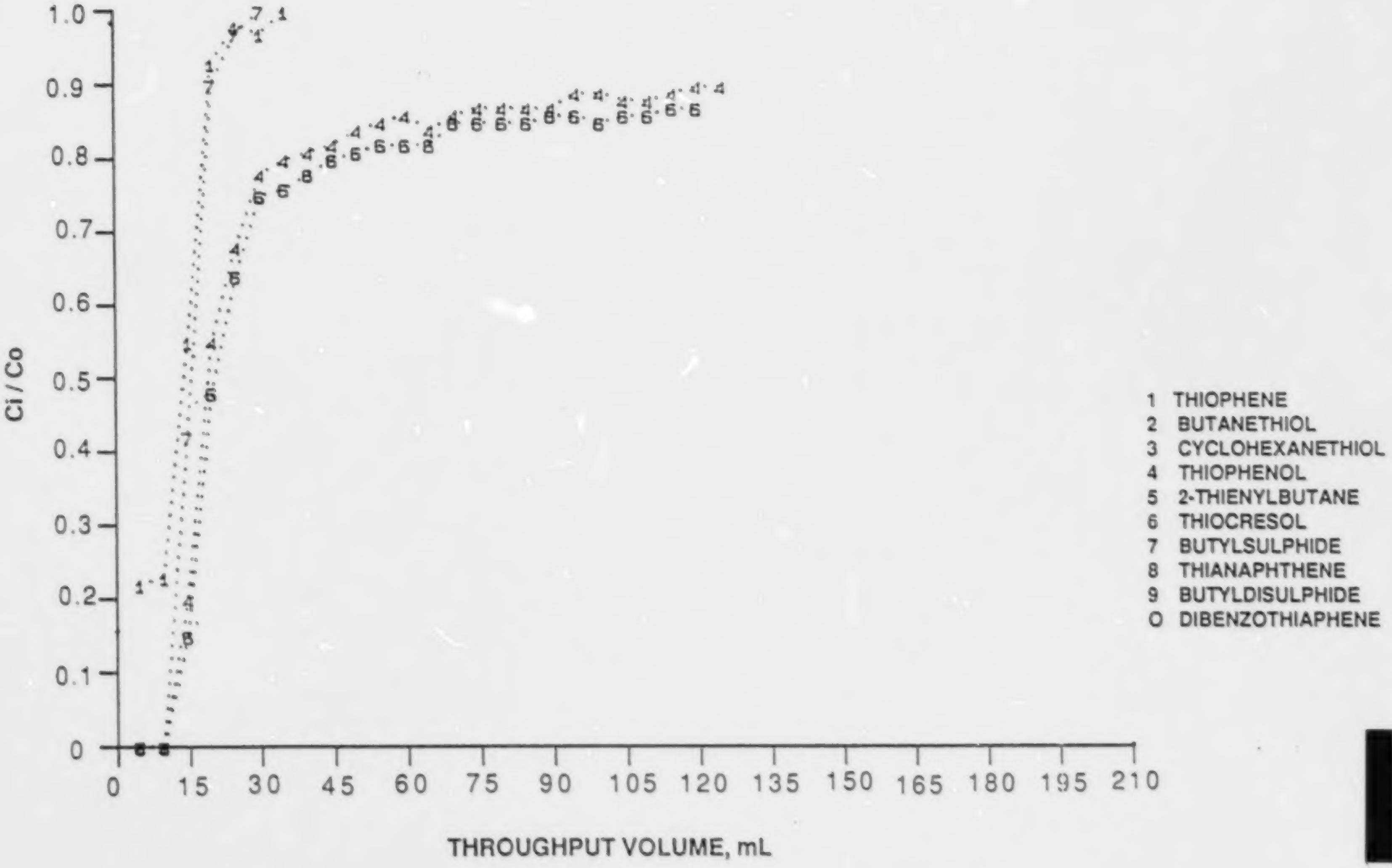


TABLE 5.11.5 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Attapulgite Chlorhydrol Nickel

Sorbent Weight: 7.01 g   Column Bed Volume: 8.9 mL   Flowrate: 0.75 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.24	0.07		0.07						
10	0.24	0.08		0.06						
15	0.56	0.24	0.33	0.20	0.41	0.20	0.36	0.37	0.39	0.37
20	1.0	0.93	0.87	0.71	0.89	0.63	0.86	0.87	0.86	0.85
25		1.0	0.97	0.85	0.96	0.77	0.95	0.95	0.93	0.93
30			0.99	0.90	0.98	0.82	0.97	0.97	0.96	0.94
35			1.0	0.90	1.0	0.84	0.98	0.97	0.96	0.95
40				0.94		0.86	1.0	1.0	0.98	0.98
45				0.94		0.87			1.0	1.0
50				0.96		0.89				
55				0.94		0.88				
60				0.95		0.89				
65										
70				SAMPLES LOST						
75				0.94		0.89				
80				0.96		0.90				
85				0.97		0.91				
90				0.97		0.91				
95				0.96		0.91				
100				0.97		0.91				
105				0.97		0.91				
110				0.97		0.92				
115				0.97		0.91				
120				0.97		0.91				
125				0.97		0.91				
130				0.98		0.92				
135				0.97		0.90				
140				0.96		0.90				
145				0.97		0.91				
150				0.97		0.91				

FIGURE 5. 11. 5: Ci/Co FOR ATTAPULGITE CHLORHYDROL NICKEL

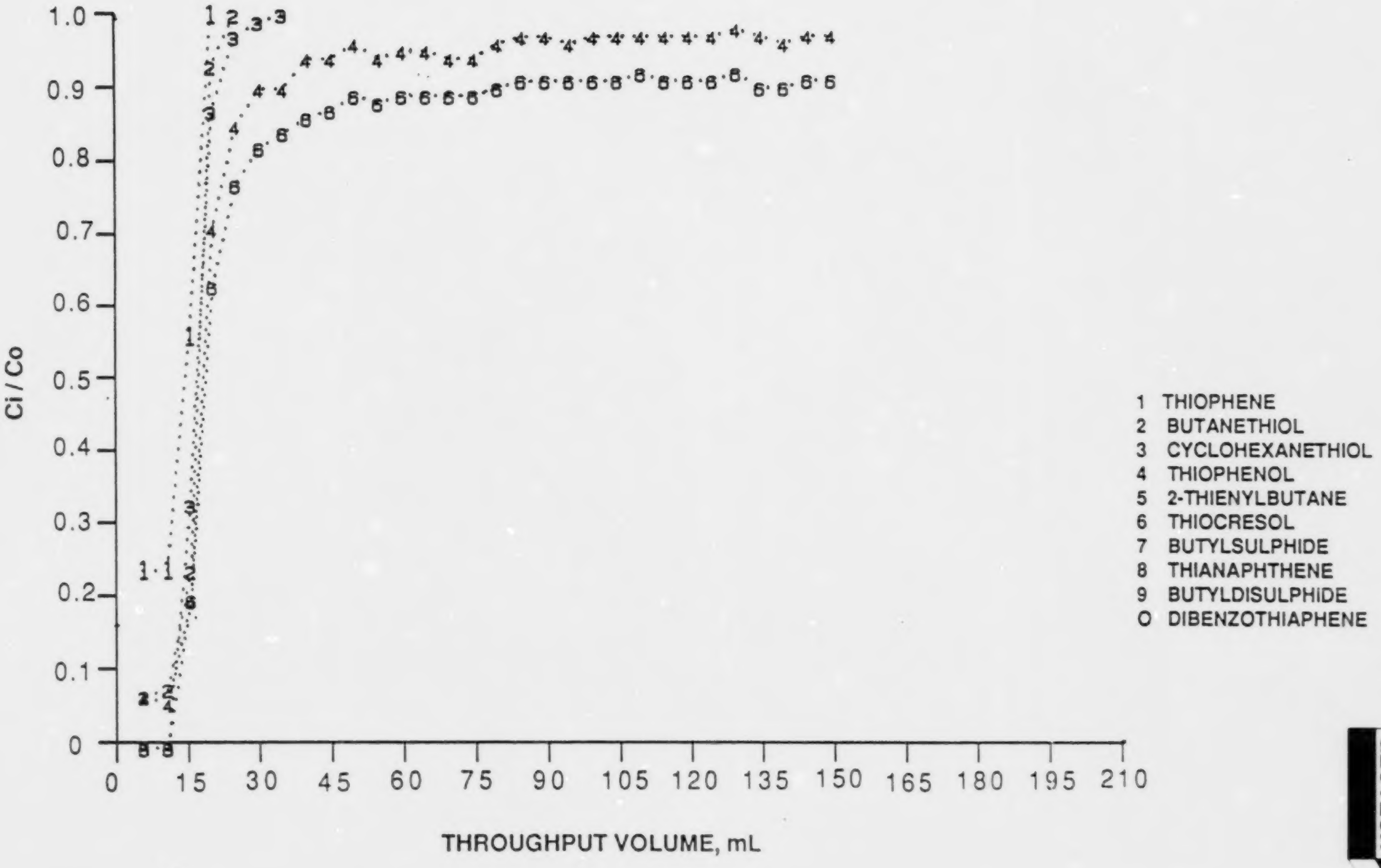


TABLE 5.11.6 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Attapulgite Chlorhydrol Zinc

Sorbent Weight: 6.95 g   Column Bed Volume: 8.8 mL   Flowrate: 0.75 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.23	0.28	0	0	0	0	0	0	0	0
10	0.22	0.06	0.05	0	0	0	0	0	0	0
15	0.56	0.32	0.35	0.04	0.49	0.05	0.43	0.45	0.48	0.46
20	0.92	0.86	0.85	0.48	0.90	0.47	0.89	0.90	0.90	0.92
25	0.98	0.95	0.96	0.77	0.98	0.70	0.97	0.97	0.96	0.96
30	1.0	0.98	0.99	0.85	1.0	0.78	1.0	1.0	1.0	1.0
35		1.0	1.0	0.89		0.83				
40				0.90		0.84				
45				0.91		0.86				
50				0.92		0.87				
55				0.94		0.89				
60				0.93		0.88				
65				0.92		0.87				
70				0.93		0.89				

FIGURE 5.11.6: Ci/Co FOR ATTAPULGITE CHLORHYDROL ZINC

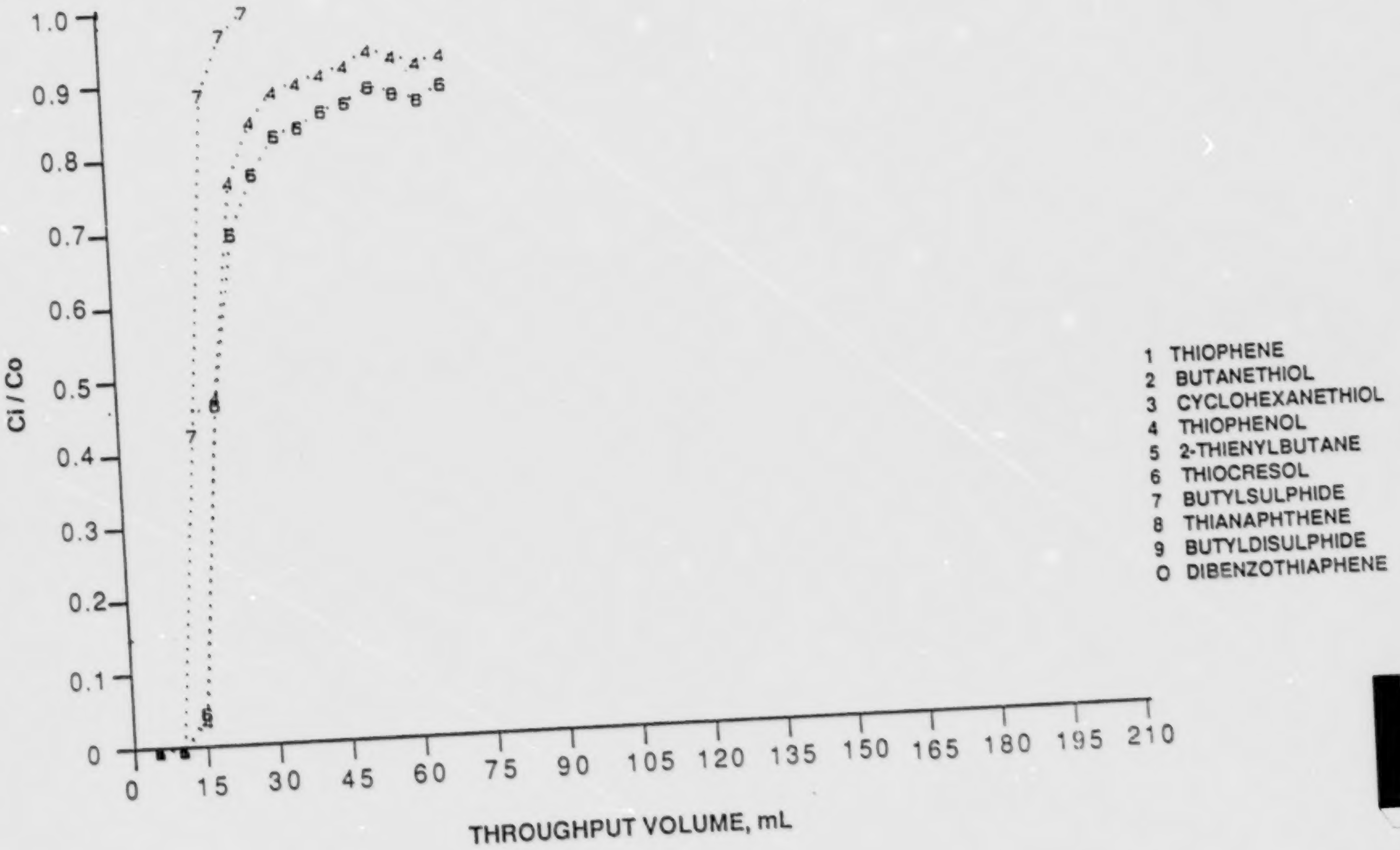


TABLE 5.12.1 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Bentonite Copper

Sorbent Weight: 15.37 g Column Bed Volume: 5.8 mL Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.39	0.08	0	0.03	0	0	0	0	0	0
10	0.49	0.06	0	0.03	0.14	0	0	0.11	0	0.11
15	0.89	0.07	0	0	0.58	0	0	0.57	0.18	0.31
20	1.0	0.20	0	0	0.74	0	0	0.76	0.34	0.76
25		0.19	0	0	0.76	0	0	0.79	0.40	0.79
30		0.19	0	0	0.79	0	0	0.82	0.47	0.82
35		0.21	0	0	0.79	0	0	0.81	0.50	0.80
40		0.20	0	0	0.79	0	0	0.82	0.54	0.81
45		0.20	0	0.03	0.80	0	0	0.83	0.58	0.82
50		0.19	0	0.04	0.80	0	0	0.83	0.61	0.83
55		0.19	0	0	0.80	0	0	0.83	0.63	0.83
60		0.19	0	0.03	0.81	0	0	0.83	0.65	0.83
65		0.20	0	0.03	0.83	0	0	0.85	0.70	0.85
70		0.19	0	0	0.82	0	0	0.84	0.71	0.84
75		0.20	0	0	0.79	0	0	0.82	0.71	0.83
80		0.19	0	0	0.81	0	0	0.83	0.73	0.84
85		0.20	0	0.03	0.80	0	0	0.83	0.74	0.83
90		0.20	0	0.03	0.80	0	0	0.82	0.74	0.83
95		0.20	0	0	0.82	0	0	0.83	0.75	0.84
100		0.21	0	0.03	0.82	0	0.04	0.83	0.76	0.84
105		0.21	0	0.04	0.82	0	0.07	0.84	0.76	0.84
110		0.20	0	0.03	0.82	0	0.10	0.84	0.77	0.93
115		0.20	0	0.03	0.82	0	0.14	0.85	0.80	0.93
120		0.20	0	0.04	0.83	0	0.18	0.85	0.77	0.85
125		0.20	0	0	0.82	0	0.21	0.84	0.77	0.85
130		0.20	0	0	0.82	0	0.24	0.84	0.77	0.85
135		0.21	0	0.04	0.82	0	0.28	0.84	0.78	0.84
140		0.22	0	0	0.83	0	0.32	0.85	0.79	0.85
145		0.20	0	0.03	0.81	0	0.35	0.81	0.78	0.90
150		0.20	0	0.04	0.81	0	0.39	0.83	0.77	0.82

FIGURE 5. 12. 1: Ci/Co FOR BENTONITE COPPER

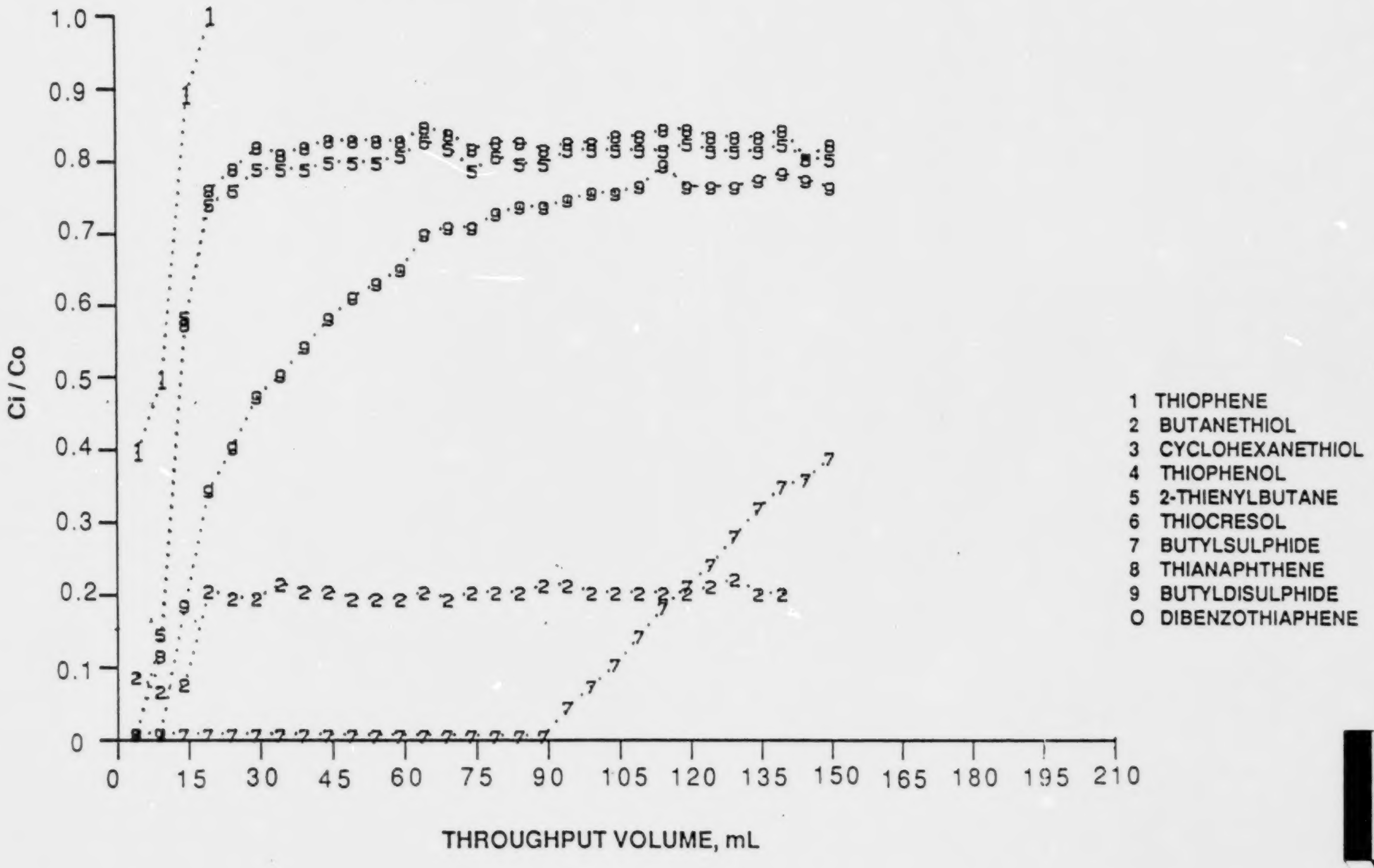


TABLE 5.12.2 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Bentonite Iron (III)

Sorbent Weight: 15.03 g Column Bed Volume: 5.6 mL Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.34	0.29	0	0.05	0	0	0	0	0	0
10	0.42	0.30	0	0.04	0.13	0	0	0.15	0.11	0.17
15	0.76	0.07	0	0	0.50	0	0.09	0.63	0.36	0.64
20	0.95	0.18	0	0	0.74	0	0.28	0.85	0.51	0.88
25	0.98	0.19	0	0	0.78	0	0.50	0.88	0.60	0.91
30	1.0	0.07	0	0	0.80	0	0.69	0.90	0.65	0.91
35		0.19	0	0	0.80	0	0.82	0.89	0.72	0.92
40		0.19	0	0	0.81	0	0.93	0.90	0.77	0.93
45		0.19	0	0	0.81	0	1.0	0.90	0.79	0.92
50		0.18	0	0	0.81	0		0.90	0.82	0.92
55		0.18	0	0	0.81	0		0.90	0.83	0.92
60		0.09	0	0	0.82	0		0.92	0.85	0.92
65		0.11	0.09	0	0.82	0.03		0.89	0.84	0.91
70		0.11	0.16	0.06	0.82	0.04		0.95	0.84	0.91
75		0.18	0.23	0.12	0.82	0.05		0.91	0.83	0.90
80		0.38	0.28	0.17	0.82	0.07		0.87	0.80	0.89
85		0.45	0.34	0.22	0.82	0.09		0.87	0.79	0.89
90		0.50	0.39	0.27	0.83	0.12		0.92	0.80	0.90
95		0.54	0.43	0.33	0.86	0.14		0.95	0.81	0.91
100		0.56	0.46	0.35	0.86	0.17		0.89	0.81	0.91
105		0.51	0.59	0.53	0.87	0.22		0.91	0.94	0.93
110		0.50	0.59	0.55	0.87	0.24		0.93	0.90	0.96
115		0.51	0.58	0.56	0.89	0.25		0.90	0.87	1.0
120		0.49	0.70	0.67	0.88	0.33		0.91	0.89	
125		0.51	0.67	0.66	0.90	0.32		0.89	0.95	
130		0.48	0.75	0.75	0.92	0.38		0.93	0.90	
135		0.57	0.65	0.65	0.90	0.33		0.92	0.86	
140		0.58	0.67	0.68	0.93	0.36		0.93	0.89	
145		0.56	0.70	0.70	0.91	0.38		0.90	0.92	
150		0.56	0.78	0.79	0.90	0.44		0.93	0.98	

FIGURE 5.12.2: Ci/Co FOR BENTONITE IRON (III)

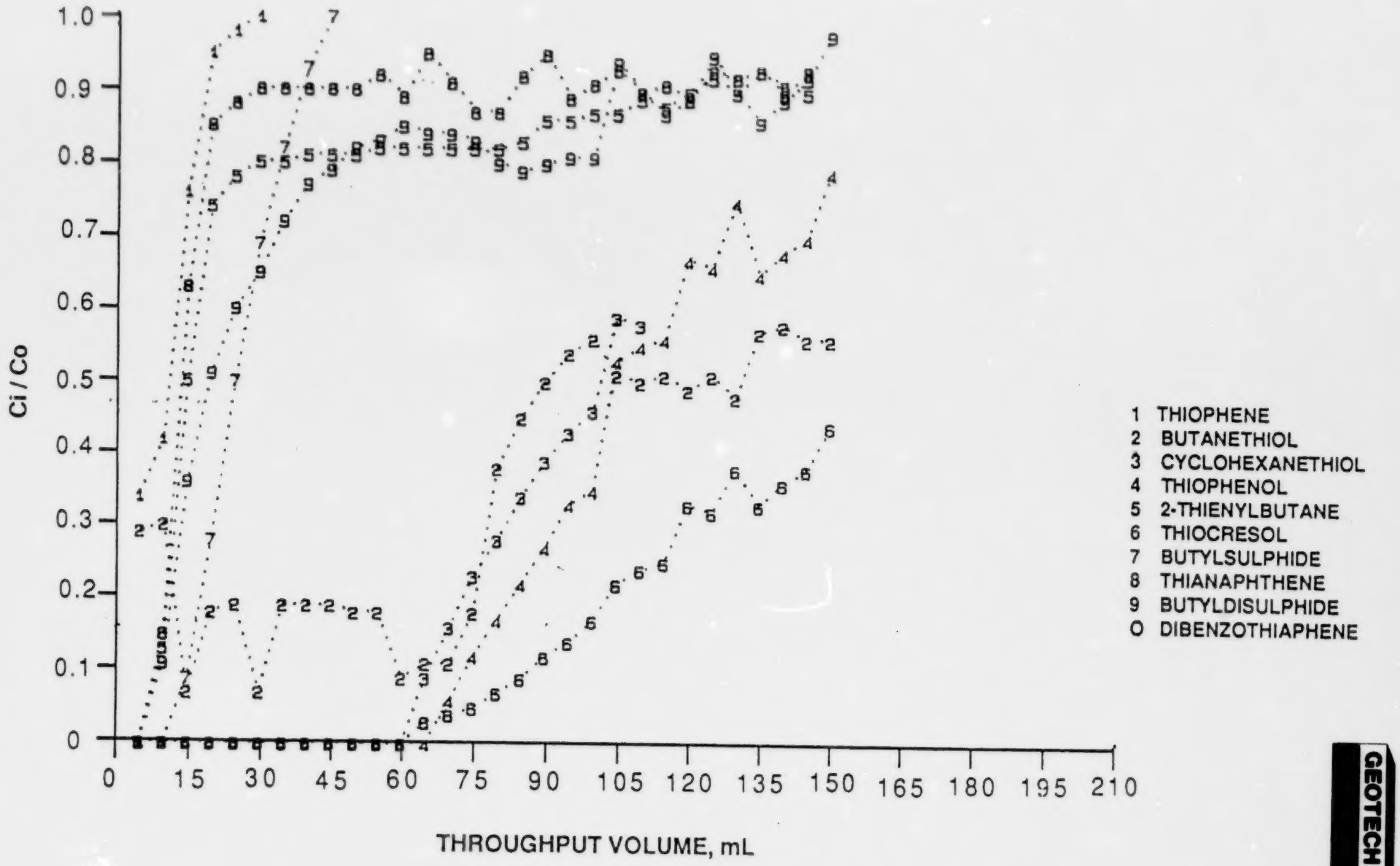


TABLE 5.12.3 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Bentonite Nickel

Sorbent Weight: 15.01 g Column Bed Volume: 6.1 mL Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.36	0.31	0	0.05	0	0	0	0	0	0
10	0.41	0.10	0.09	0.04	0.20	0.03	0.13	0.16	0.18	0.18
15	0.74	0.66	0.59	0.40	0.77	0.40	0.67	0.73	0.76	0.77
20	0.92	0.92	0.90	0.71	0.87	0.67	0.95	0.96	0.96	0.98
25	0.99	0.95	0.92	0.78	0.97	0.73	0.97	0.97	0.97	0.96
30	0.99	0.98	0.96	0.83	0.99	0.78	1.0	1.0	1.0	1.0
35	1.0	0.99	0.96	0.84	0.99	0.79				
40		1.0	0.96	0.86	0.99	0.81				
45			0.97	0.87	1.0	0.82				
50			0.97	0.87		0.82				
55			0.98	0.89		0.84				
60			0.98	0.89		0.84				
65			1.0	0.90		0.87				
70				0.91		0.88				
75				0.89		0.86				
80				0.90		0.87				
85				0.94		0.90				
90				0.89		0.87				

COMMENTS:

Thiophenal and thiocresol remained essentially constant to the conclusion of the test.

FIGURE 5.12.3: Ci/Co FOR BENTONITE NICKEL

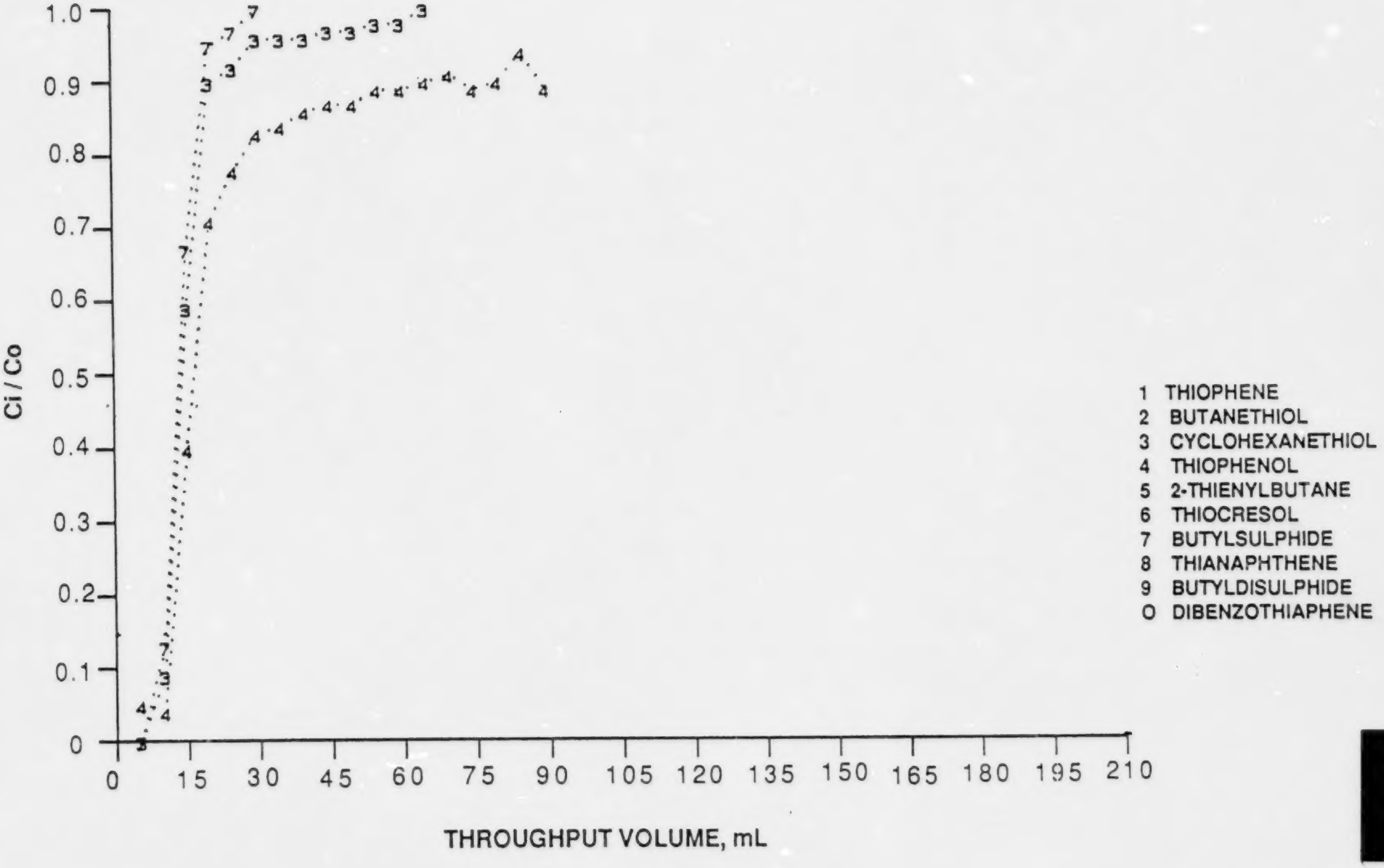


TABLE 5.12.4 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Bentonite Zinc

Sorbent Weight: 14.09 g   Column Bed Volume: 6.9 mL   Flowrate: 0.58 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.33	0.34	0	0.06	0	0	0	0	0	0
10	0.38	0.33	0	0.05	0.27	0	0	0.21	0.18	0.24
15	0.61	0.07	0	0	0.79	0	0.18	0.74	0.64	0.79
20	0.83	0.29	0	0	0.97	0	0.48	0.97	0.85	0.99
25	0.87	0.08	0	0	1.0	0	0.69	1.0	0.91	1.0
30	0.89	0.21	0	0		0	0.80		0.93	
35	0.90	0.08	0	0		0	0.85		0.94	
40	0.89	0.19	0	0		0	0.84		0.89	
45	0.94	0.19	0	0		0	0.88		0.92	
50	0.87	0.08	0	0		0	0.90		0.91	
55	0.92	0.27	0	0		0	0.90		0.91	
60	0.90	0.27	0	0		0	0.87		0.88	
65	0.97	0.20	0	0		0	0.88		0.91	
70	0.93	0.17	0	0		0	0.87		0.88	
75	0.86	0.09	0	0		0	0.86		0.87	
80	0.93	0.19	0	0		0	0.88		0.88	
85	0.98	0.19	0	0		0	0.89		0.88	
90	0.98	0.12	0.14	0.04		0	0.89		0.89	
95	0.95	0.12	0.36	0.13		0.09	0.92		0.91	
100	0.94	0.17	0.57	0.25		0.18	0.94		0.92	
105	0.96	0.42	0.73	0.36		0.27	0.96		0.92	
110	0.98	0.51	0.83	0.46		0.36	0.97		0.90	
115	0.97	0.57	0.89	0.55		0.43	0.98		0.90	
120	0.89	0.65	0.94	0.62		0.50	0.99		0.91	
125	0.94	0.67	0.97	0.66		0.56	1.0		0.91	
130	0.99	0.74	1.0	0.73		0.61			0.91	
135	0.96	0.76		0.77		0.64			0.90	
140	0.95	0.78		0.77		0.68			0.90	
145	0.97	0.83		0.80		0.70			0.89	
150	1.0	0.87		0.84		0.73			0.90	
155		0.87		0.85		0.74			0.89	
160		0.91		0.87		0.77			0.88	
165		0.91		0.89		0.78			0.87	
170		0.96		0.93		0.82			0.89	
175		0.95		0.93		0.84			0.88	

FIGURE 5. 12. 4: Ci/Co FOR BENTONITE ZINC

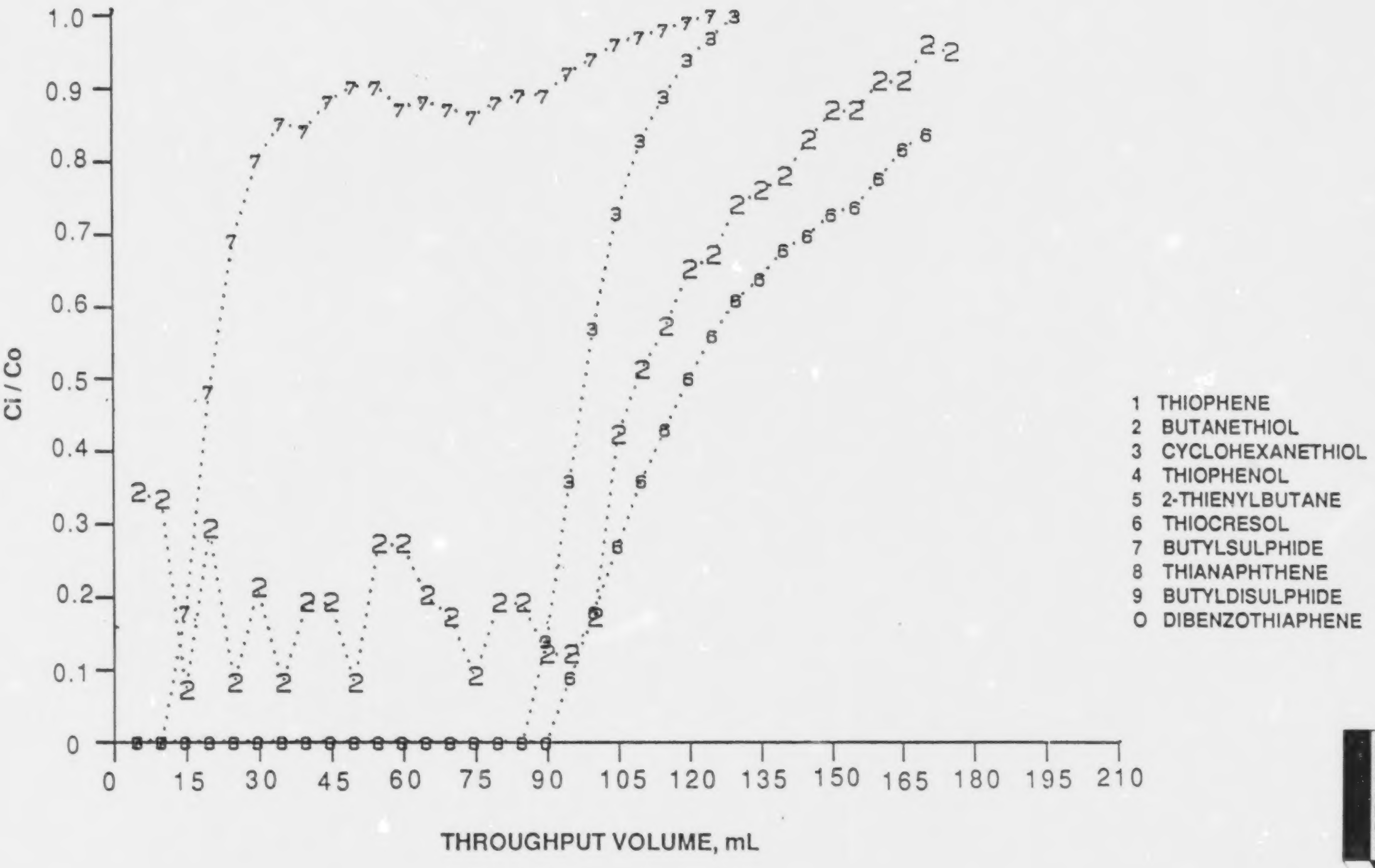


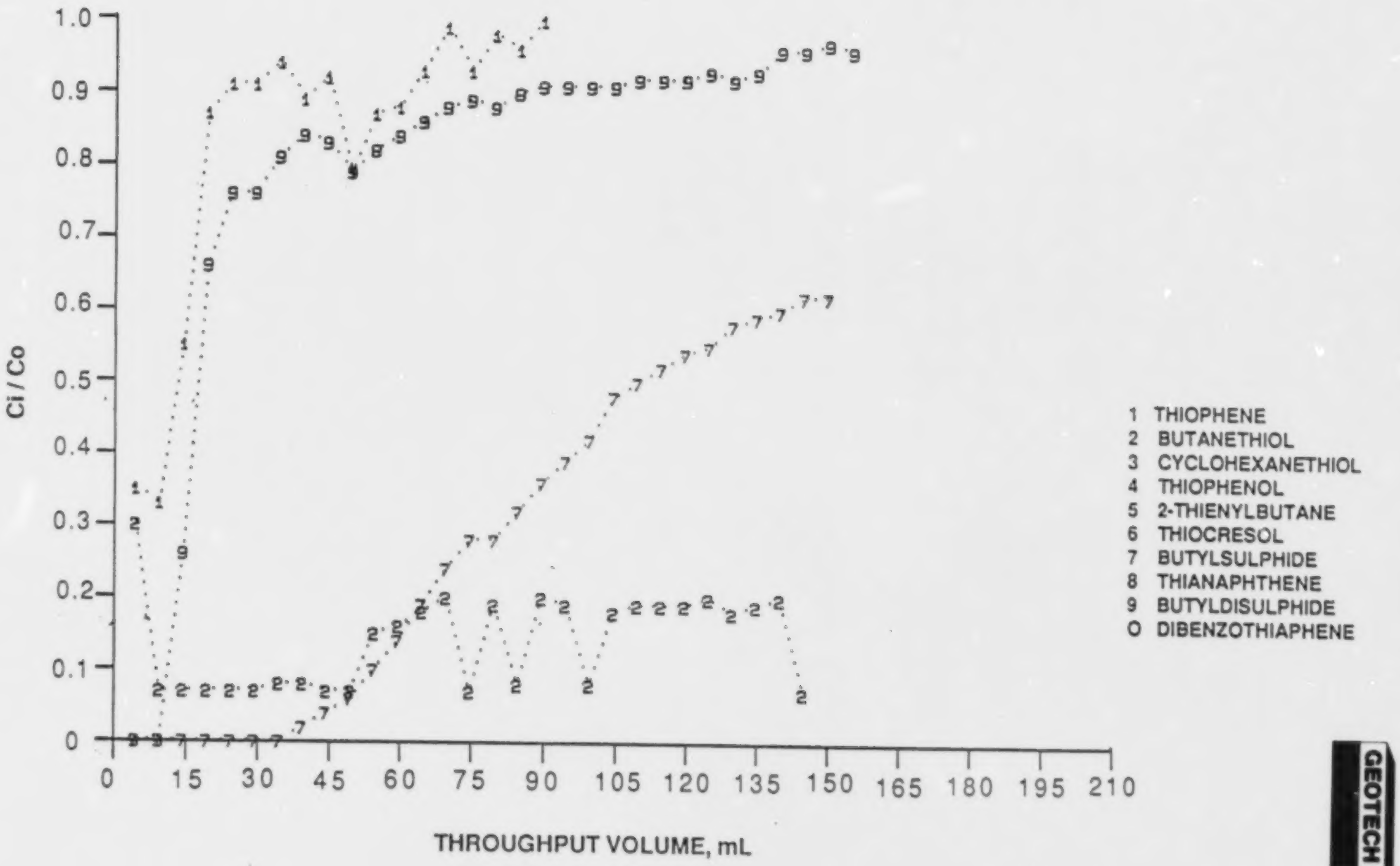
TABLE 5.13.1 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Bentonite Chlorhydrol Copper

Sorbent Weight: 15.10 g   Column Bed Volume: 5.9 mL   Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.35	0.30	0	0.05	0.02	0	0	0.02	0	0.02
10	0.33	0.07	0	0.05	0.03	0	0	0.03	0	0.02
15	0.55	0.07	0	0.04	0.44	0	0	0.40	0.26	0.41
20	0.87	0.07	0	0	0.82	0	0	0.82	0.66	0.82
25	0.91	0.07	0	0	0.88	0	0	0.90	0.76	0.90
30	0.91	0.07	0	0	0.89	0	0	0.89	0.76	0.91
35	0.94	0.08	0	0	0.89	0	0	0.91	0.81	0.92
40	0.89	0.08	0	0.04	0.90	0	0.02	0.91	0.84	0.93
45	0.92	0.07	0	0.04	0.89	0	0.04	0.93	0.83	0.93
50	0.79	0.07	0	0	0.82	0	0.06	0.89	0.79	0.90
55	0.87	0.15	0	0	0.86	0	0.1	0.91	0.82	0.91
60	0.88	0.16	0	0	0.86	0	0.14	0.87	0.84	0.92
65	0.93	0.18	0	0	0.89	0	0.19	0.92	0.86	0.93
70	0.99	0.20	0	0	0.91	0	0.24	0.95	0.88	0.93
75	0.93	0.07	0	0	0.89	0	0.28	0.91	0.89	0.94
80	0.98	0.19	0	0	0.88	0	0.28	0.91	0.88	0.93
85	0.96	0.08	0	0	0.90	0	0.32	0.90	0.90	0.94
90	1.0	0.20	0	0.04	0.90	0	0.36	0.92	0.91	0.93
95		0.19	0	0.04	0.90	0	0.39	0.92	0.91	0.94
100		0.08	0	0.04	0.89	0	0.42	0.91	0.91	0.93
105		0.18	0	0.04	0.89	0	0.45	0.91	0.91	0.93
110		0.19	0	0.04	0.90	0	0.48	0.91	0.92	0.94
115		0.19	0	0.04	0.89	0	0.50	0.90	0.92	0.93
120		0.19	0	0.04	0.88	0	0.52	0.90	0.92	0.92
125		0.20	0	0.04	0.89	0	0.54	0.91	0.93	0.92
130		0.18	0	0	0.87	0	0.55	0.89	0.92	0.91
135		0.19	0	0	0.87	0	0.58	0.90	0.93	0.92
140		0.18	0	0.04	0.90	0	0.59	0.92	0.96	0.93
145		0.19	0	0	0.89	0	0.60	0.91	0.96	0.93
150		0.20	0	0.04	0.90	0	0.62	0.92	0.97	0.93
155		0.07	0	0.04	0.89	0	0.62	0.91	0.96	0.93

FIGURE 5.13.1: Ci/Co FOR BENTONITE CHLORHYDROL COPPER



GEOTECH

TABLE 5.13.2 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Bentonite Chlorhydrol Iron (III)

Sorbent Weight: 14.86 g Column Bed Volume: 5.6 mL Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.46	0.26	0	0	0	0	0	0	0	0
10	0.53	0.26	0	0.04	0.09	0	0	0.12	0.09	0.13
15	0.94	0.06	0	0	0.44	0	0.10	0.63	0.37	0.62
20	1.0	0.06	0	0	0.69	0	0.27	0.86	0.52	0.85
25		0.17	0	0	0.75	0	0.48	0.92	0.60	0.89
30		0.17	0	0	0.79	0	0.80	0.94	0.74	0.94
35		0.16	0	0	0.76	0	0.63	0.96	0.68	0.89
40		0.17	0	0	0.77	0	0.89	0.92	0.73	0.89
45		0.06	0	0	0.78	0	0.90	0.93	0.78	0.90
50		0.06	0.06	0	0.79	0	0.90	0.94	0.80	0.94
55		0.18	0.10	0	0.77	0	0.95	0.91	0.76	0.88
60		0.18	0.15	0.05	0.78	0	0.96	0.95	0.78	0.92
65		0.19	0.20	0.08	0.79	0.05	0.96	0.98	0.80	0.96
70		0.20	0.29	0.11	0.80	0.08	1.0	1.0	0.85	0.97
75		0.25	0.35	0.15	0.81	0.10			0.87	0.99
80		0.30	0.41	0.21	0.90	0.15			0.88	1.0
85		0.40	0.45	0.25	0.95	0.18			0.89	
90		0.54	0.51	0.34	0.99	0.23			0.89	

COMMENTS:

Values remained essentially constant through the duration of the test.

FIGURE 5.13.2: Ci/Co FOR BENTONITE CHLORHYDROL IRON (III)

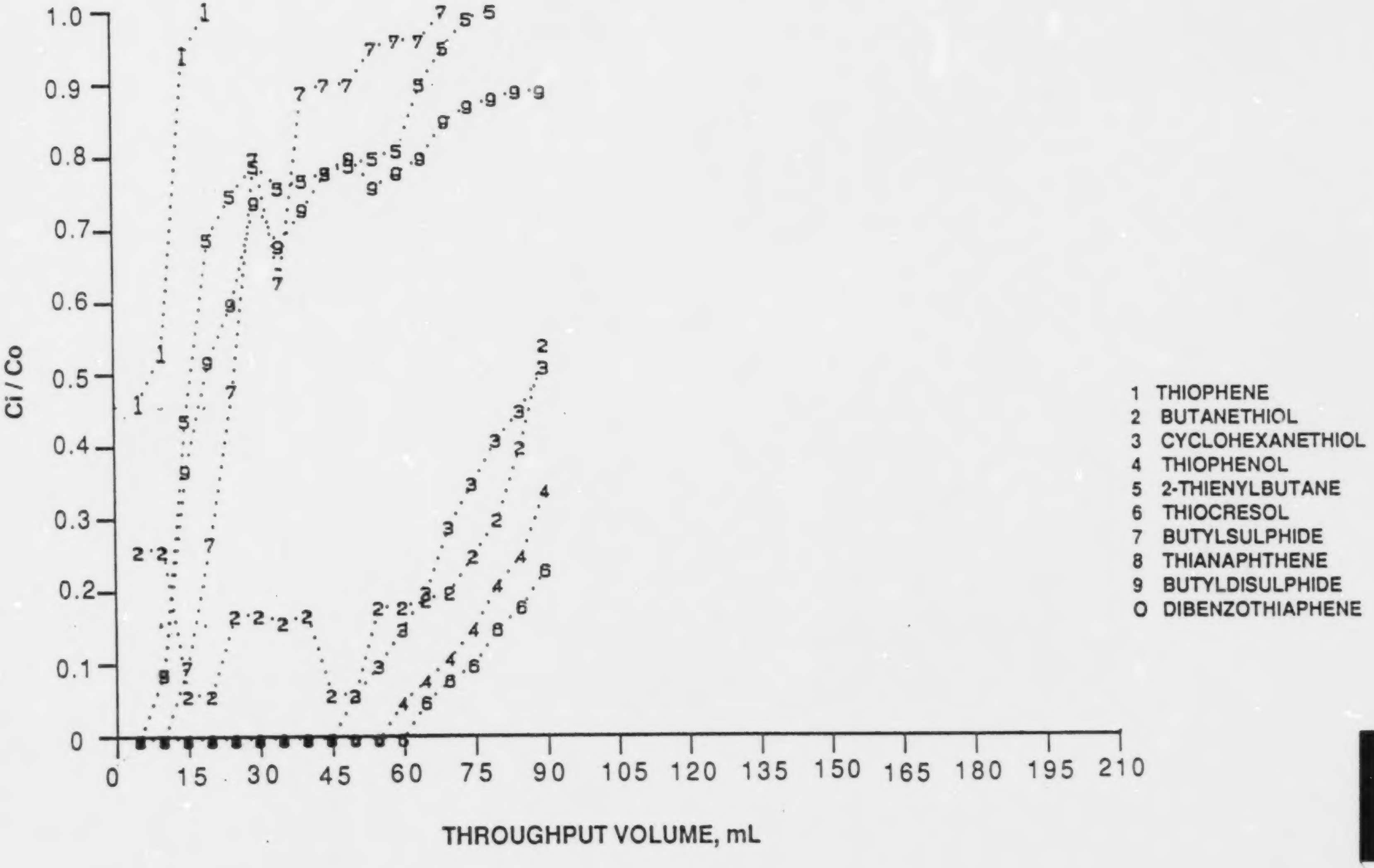


TABLE 5.13.4 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Bentonite Chlorhydrol Nickel

Sorbent Weight: 15.37 g Column Bed Volume: 6.0 mL Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.34	0.07	0	0.04	0	0	0	0	0	0
10	0.38	0.08	0.04	0.05	0.13	0.03	0.07	0.12	0.14	0.14
15	0.67	0.48	0.40	0.37	0.51	0.30	0.49	0.59	0.59	0.62
20	0.88	0.79	0.72	0.65	0.74	0.60	0.82	0.89	0.81	0.89
25	0.97	0.89	0.82	0.76	0.86	0.71	0.90	0.92	0.88	0.92
30	1.0	0.95	0.87	0.81	0.91	0.76	0.93	0.94	0.92	0.94
35		0.93	0.88	0.85	0.92	0.80	0.93	0.94	0.93	0.94
40		0.96	0.95	0.94	0.97	0.89	0.98	0.99	0.99	0.99
45		1.0	1.0	1.0	1.0	0.95	1.0	1.0	1.0	1.0
50						1.0				

FIGURE 5.13.4: Ci/Co FOR BENTONITE CHLORHYDROL NICKEL

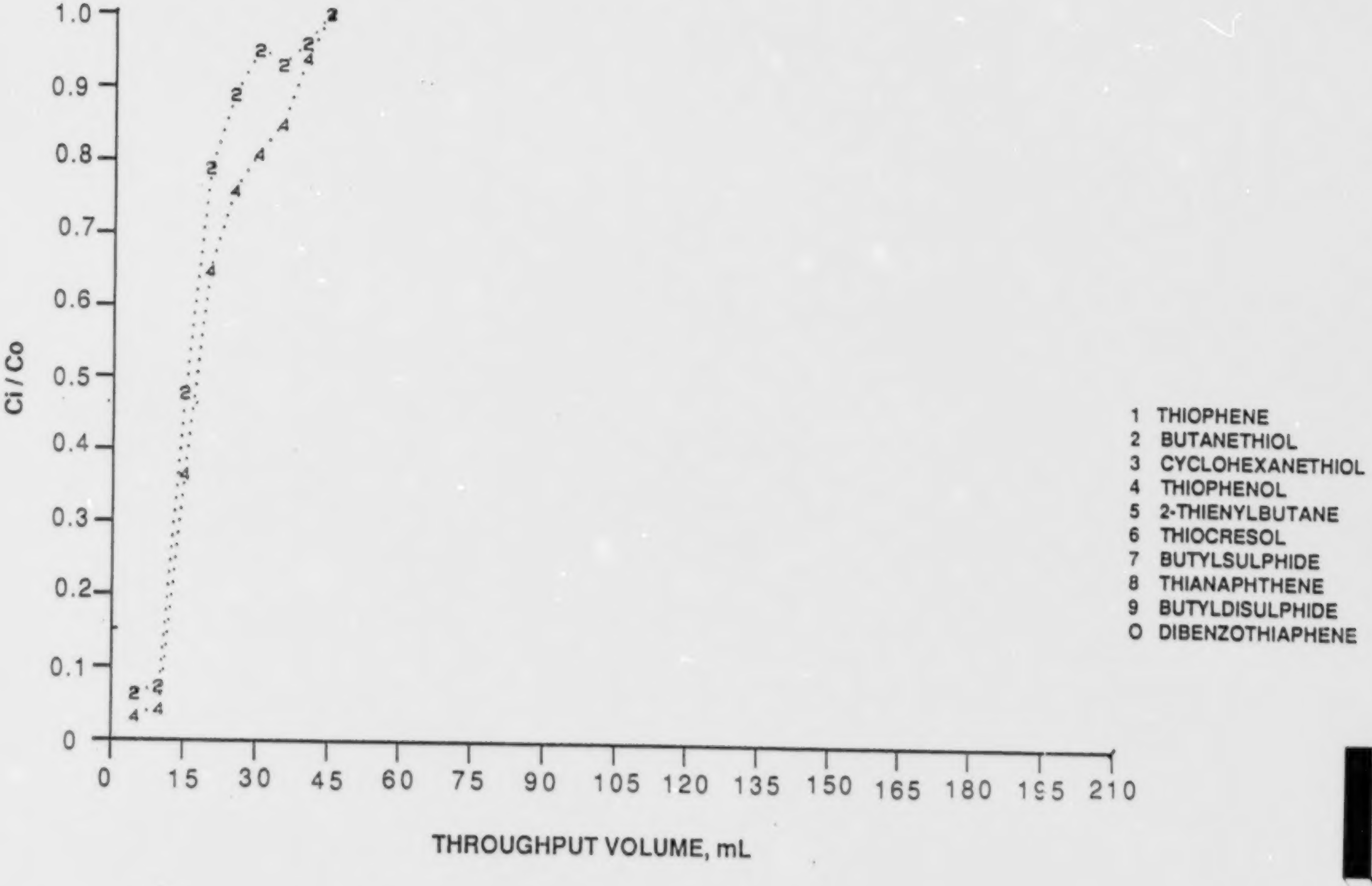


TABLE 5.13.5 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Bentonite Chlorhydrol Zinc

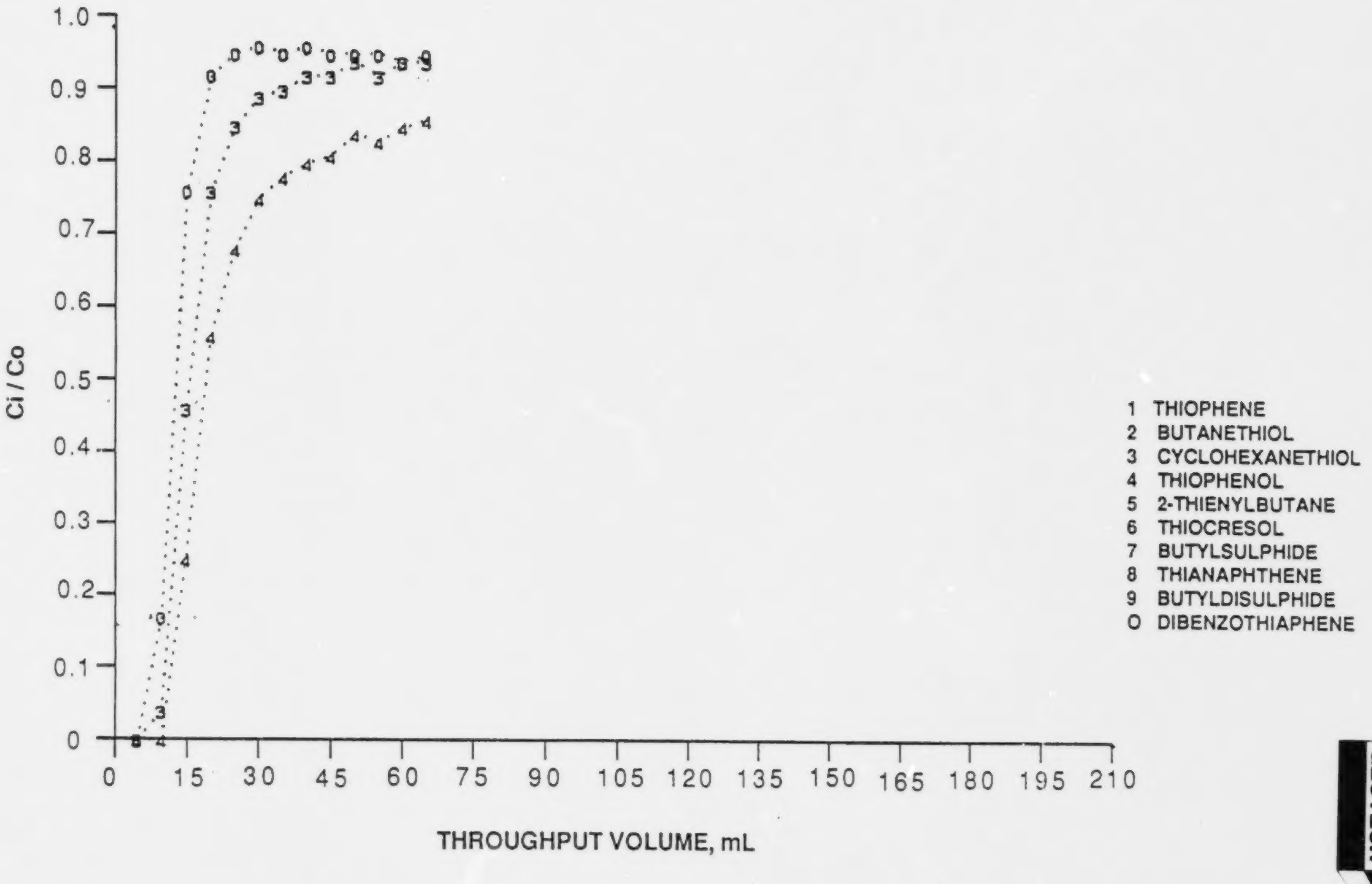
Sorbent Weight: 15.18 g   Column Bed Volume: 6.3 mL   Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.34	0.28	0	0	0	0	0	0	0	0
10	0.39	0.30	0.04	0	0.19	0	0.11	0.14	0.17	0.17
15	0.74	0.48	0.46	0.25	0.76	0.24	0.64	0.73	0.78	0.76
20	0.89	0.73	0.76	0.56	0.90	0.50	0.86	0.91	0.94	0.92
25	0.92	0.82	0.85	0.68	0.92	0.63	0.92	0.94	0.97	0.95
30	0.93	0.86	0.89	0.75	0.94	0.70	0.94	0.95	0.98	0.96
35	0.97	0.90	0.90	0.78	0.94	0.73	0.93	0.94	0.99	0.95
40	0.99	0.93	0.92	0.80	0.95	0.77	0.94	0.95	0.99	0.96
45	0.98	0.92	0.92	0.81	0.94	0.78	0.93	0.94	0.97	0.95
50	0.98	0.94	0.94	0.84	0.95	0.81	0.95	0.95	0.99	0.95
55	0.99	0.94	0.92	0.83	0.94	0.81	0.94	0.94	0.98	0.95
60	1.0	0.96	0.94	0.85	0.94	0.83	0.94	0.94	0.98	0.94
65		0.96	0.94	0.86	0.94	0.83	0.95	0.95	0.98	0.95

COMMENTS:

Values remained essentially constant through the duration of the test.

FIGURE 5.13.5: Ci/Co FOR BENTONITE CHLORHYDROL ZINC



GEOTECH

TABLE 5.14.1 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Calcium Montmorillonite Copper

Sorbent Weight: 16.13 g Column Bed Volume: 5.0 mL Flowrate: 0.42 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.31	0.09	0	0.03	0.07	0	0.02	0.06	0.05	0.06
10	0.63	0.09	0	0.03	0.51	0	0.02	0.44	0.39	0.45
15	0.94	0.09	0	0.03	0.80	0	0.02	0.77	0.71	0.77
20	1.0	0.09	0	0	0.82	0	0.02	0.82	0.75	0.85
25		0.09	0	0	0.81	0	0.02	0.79	0.71	0.76
30		0.09	0	0	0.81	0	0.05	0.80	0.72	0.77
35		0.09	0	0	0.83	0	0.06	0.83	0.73	0.79
40		0.09	0	0	0.73	0	0.09	0.70	0.61	0.70
45		0.09	0	0.02	0.85	0	0.14	0.87	0.79	0.89
50		0.09	0	0.02	0.85	0	0.16	0.85	0.74	0.79
55		0.09	0	0	0.82	0	0.19	0.82	0.71	0.75
60		0.09	0	0	0.81	0	0.21	0.80	0.71	0.75
65		0.09	0	0	0.78	0	0.23	0.76	0.67	0.70
70		0.09	0	0	0.79	0	0.26	0.79	0.70	0.75
75		0.09	0	0	0.79	0	0.28	0.79	0.71	0.75
80		0.09	0	0	0.80	0	0.30	0.79	0.72	0.76
85		0.05	0	0	0.88	0	0.46	0.88	0.89	0.87
90		0.05	0	0	0.96	0	0.51	0.95	0.96	0.92
95		0.06	0	0	1.0	0	0.52	1.0	1.0	0.97
100		0.05	0	0		0	0.53			1.0
105		0.06	0	0		0	0.57			
110		0.06	0	0		0	0.60			
115		0.06	0	0		0	0.64			
120		0.07	0	0		0	0.69			
125		0.06	0	0		0	0.64			

FIGURE 5.14.1: Ci/Co FOR CALCIUM MONTMORILLONITE COPPER

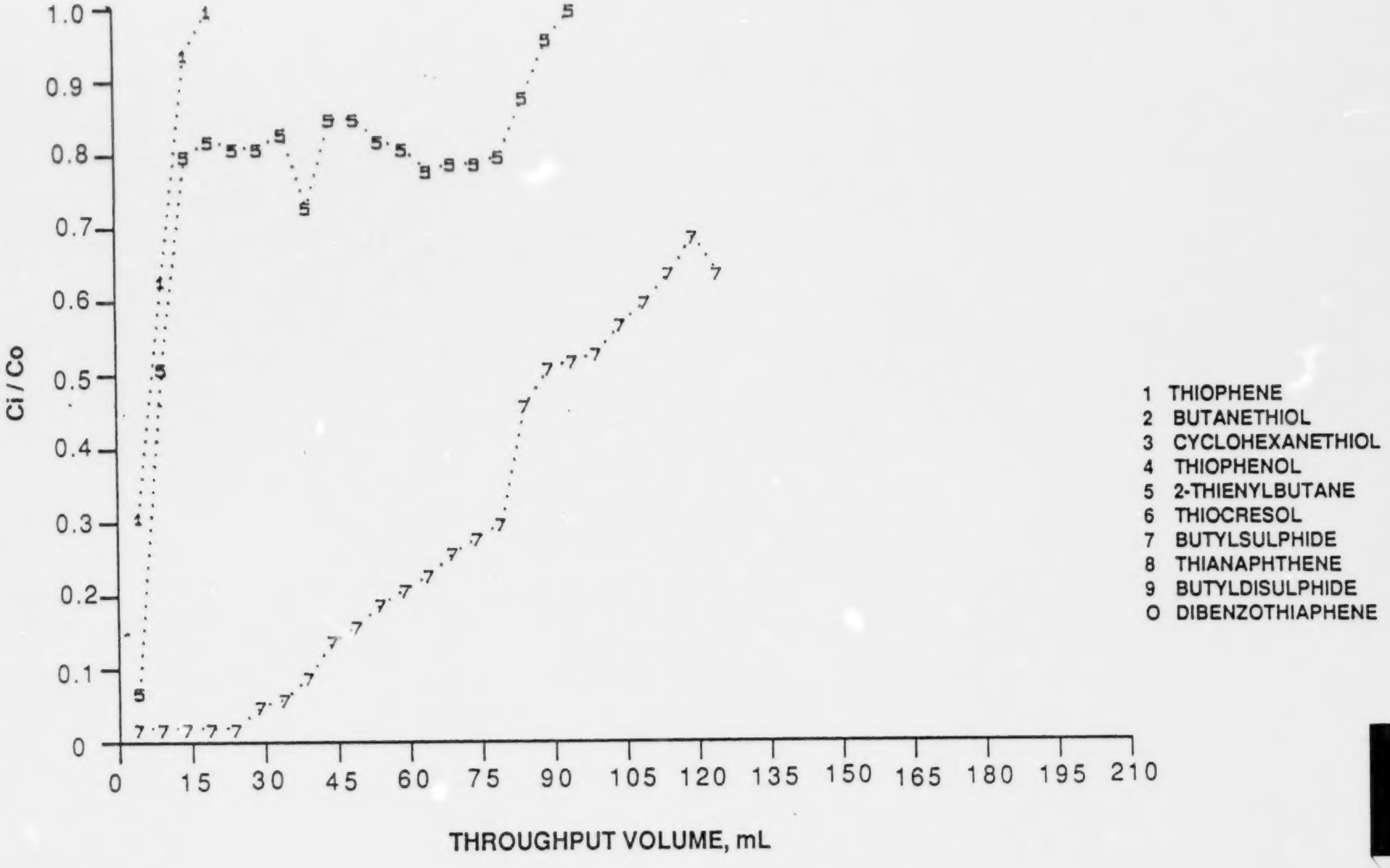


TABLE 5.14.2 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Calcium Montmorillonite Iron (III)

Sorbent Weight: 15.73 g Column Bed Volume: 6.7 mL Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.23	0		0	0	0	0	0	0	0
10	0.30	0		0	0	0	0	0.12	0.10	0.14
15	0.66	0		0	0.45	0	0.17	0.51	0.36	0.54
20	0.90	0		0	0.67	0	0.32	0.76	0.50	0.75
25	0.92	0		0	0.71	0	0.42	0.82	0.55	0.81
30	0.98	0		0	0.69	0	0.47	0.77	0.53	0.75
35	1.0	0		0	0.78	0	0.61	0.88	0.63	0.85
40		0		0	0.84	0	0.72	0.96	0.71	0.95
45		0		0	0.75	0	0.68	0.85	0.63	0.83
50		0		0	0.75	0	0.70	0.83	0.64	0.83
55		0		0	0.74	0	0.73	0.84	0.65	0.83
60		0		0	0.74	0	0.75	0.84	0.67	0.83
65		0		0	0.77	0	0.79	0.86	0.70	0.84
70		0		0	0.81	0	0.86	0.90	0.76	0.91
75		0		0	0.81	0	0.87	0.91	0.79	0.93
80		0		0	0.76	0	0.81	0.83	0.73	0.82
85		0		0	0.73	0	0.78	0.81	0.70	0.78
90		0.06	0.03	0	0.79	0	0.83	0.86	0.77	0.84
95		0.06	0.04	0	0.79	0	0.83	0.86	0.77	0.85
100		0.06	0.06	0	0.79	0	0.82	0.86	0.78	0.85
105		0.04	0.07	0	0.75	0	0.78	0.80	0.73	0.77
110		0.05	0.10	0	0.78	0	0.81	0.85	0.79	0.84
115		0.24	0.12	0	0.78	0	0.80	0.83	0.77	0.83
120		0.04	0.15	0	0.82	0	0.84	0.88	0.82	0.87
125		0.08	0.18	0	0.84	0	0.87	0.90	0.86	0.92
130		0	0.18	0	0.79	0	0.83	0.86	0.80	0.86
135		0	0.19	0	0.78	0	0.83	0.84	0.80	0.84
140		0	0.20	0	0.78	0	0.83	0.84	0.78	0.8[illegible]
145		0.11	0.21	0	0.79	0	0.83	0.84	0.77	0.8[illegible]
150		0.13	0.22	0	0.77	0	0.80	0.80	0.73	0.7[illegible]

FIGURE 5. 14. 2: Ci/Co FOR CALCIUM MONTMORILLONITE IRON (III)

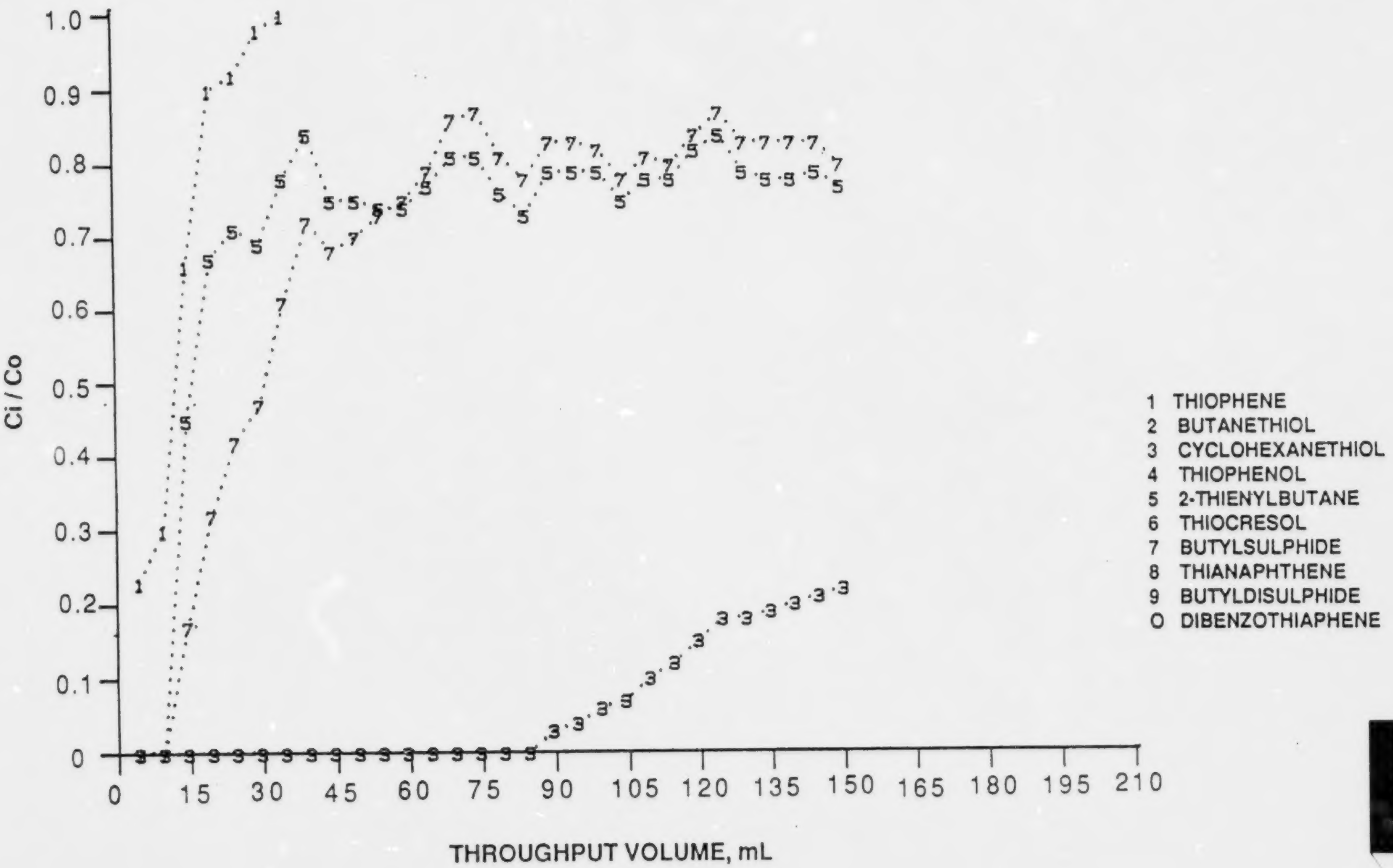


TABLE 5.14.3 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Calcium Montmorillonite Mercury

Sorbent Weight: 10.37 g   Column Bed Volume: 7.2 mL   Flowrate: 0.58 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.32	0	0	0.04	0	0	0	0	0	0
10	0.35	0	0	0.05	0.10	0	0.06	0.06	0.08	0.07
15	0.61	0.55	0.50	0.33	0.67	0.35	0.59	0.59	0.65	0.61
20	0.86	0.88	0.88	0.69	0.94	0.65	0.91	0.93	0.94	0.93
25	0.95	1.0	0.99	0.83	1.0	0.77	1.0	1.0	1.0	0.99
30	0.97		1.0	0.87		0.79				1.0
35	0.94			0.83		0.79				
40	0.95			0.86		0.80				
45	0.95			0.87		0.81				
50	0.95			0.87		0.83				
55	0.94			0.87		0.82				
60	0.94			0.88		0.83				
65	0.96			0.90		0.85				
70	0.95			0.89		0.84				
75	0.97			0.90		0.85				
80	0.92			0.84		0.81				
85	0.95			0.85		0.86				
90	0.97			0.87		0.88				
95	0.96			0.88		0.88				
100	0.92			0.90		0.89				
105	0.97			0.93		0.90				
110	0.97			0.96		0.92				
115	1.0			0.98		0.94				
120				1.0		0.95				
125						0.92				
130						0.96				
135						0.96				
140						0.94				
145						0.93				
150						0.94				
155						0.95				
160						0.95				
165						0.94				

FIGURE 5.14.3: Ci/Co FOR CALCIUM MONTMORILLONITE MERCURY

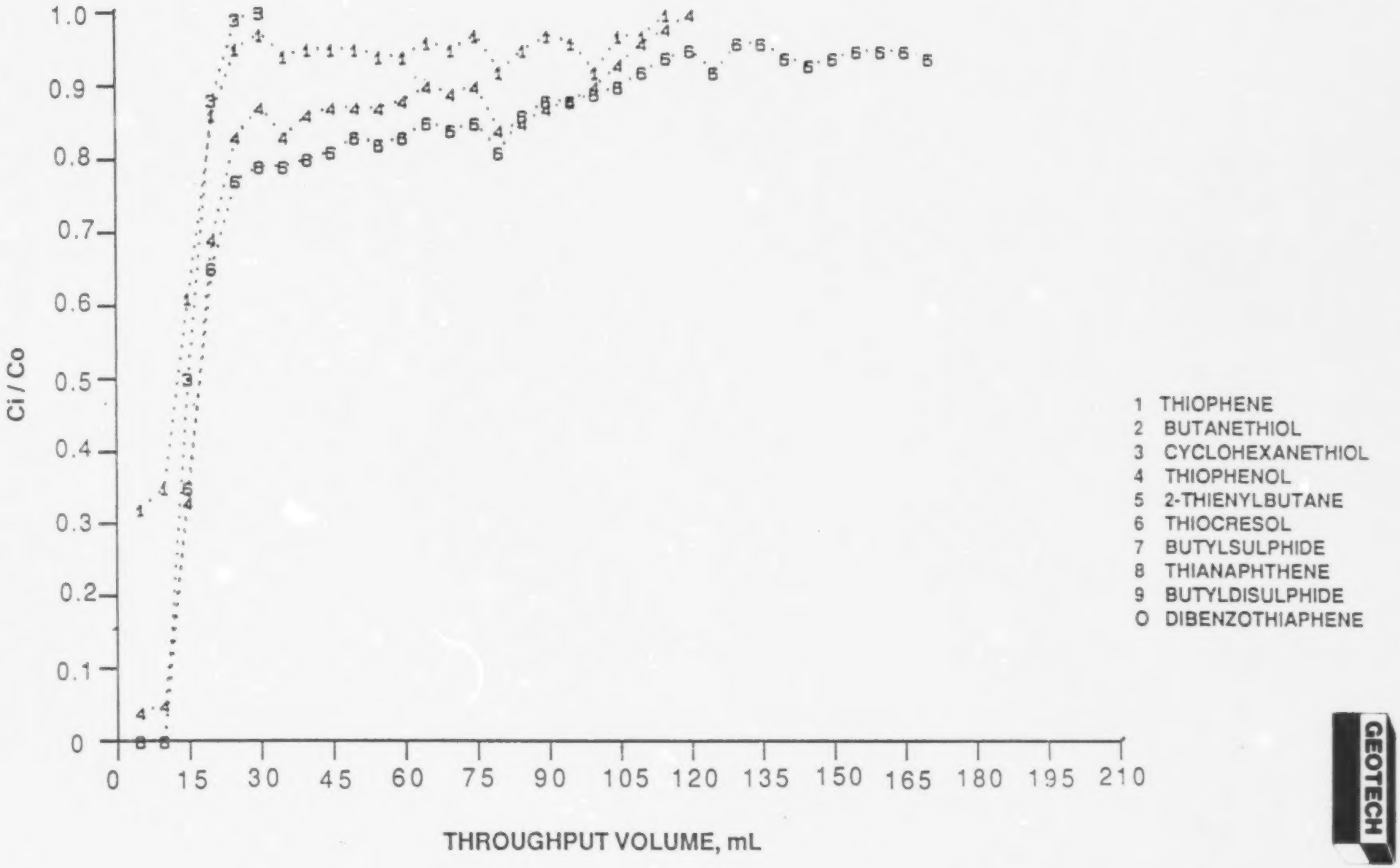


TABLE 5.14.4 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Calcium Montmorillonite Nickel

Sorbent Weight: 10.17 g Column Bed Volume: 7.8 mL Flowrate: 0.67 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.33	0.32	0	0	0	0	0	0	0	0
10	0.33	0.07	0	0	0.04	0	0	0.05	0	0.06
15	0.62	0.12	0.10	0.13	0.58	0.12	0	0.61	0.11	0.63
20	0.93	0.68	0.48	0.48	0.93	0.46	0	0.98	0.27	0.97
25	0.93	1.0	0.61	0.62	0.93	0.58	0.20	1.0	0.34	1.0
30	0.99		0.67	0.71	0.98	0.65	0.57		0.38	
35	1.0		0.62	0.66	0.94	0.63	0.75		0.36	
40			0.63	0.70	0.94	0.65	0.83		0.37	
45			0.66	0.74	0.97	0.68	0.88		0.37	
50			0.67	0.74	0.99	0.71	0.92		0.38	
55			0.68	0.76	1.0	0.71	0.94		0.38	
60			0.69	0.78		0.73	0.96		0.38	
65			0.68	0.77		0.72	0.95		0.38	
70			0.65	0.73		0.71	0.92		0.37	
75			0.62	0.71		0.68	0.89		0.36	
80			0.67	0.76		0.73	0.94		0.38	
85			0.68	0.79		0.73	0.96		0.38	
90			0.68	0.77		0.73	0.96		0.37	
95			0.69	0.80		0.75	0.97		0.38	
100			0.68	0.81		0.75	0.98		0.38	
105			0.70	0.82		0.76	0.99		0.39	
110			0.71	0.83		0.78	1.0		0.39	
115			0.70	0.82		0.77			0.39	
120			0.71	0.85		0.78			0.39	
125			0.70	0.83		0.78			0.39	
130			0.70	0.82		0.78			0.39	

TABLE 5.14.4 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Calcium Montmorillonite Nickel

Sorbent Weight: 10.17 g Column Bed Volume: 7.8 mL Flowrate: 0.67 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
135			0.73	0.88		0.82			0.39	
140			0.71	0.85		0.79			0.39	
145			0.69	0.83		0.79			0.38	
150			0.69	0.83		0.78			0.38	
155			0.69	0.83		0.80			0.39	
160			0.70	0.84		0.80			0.38	
165			0.70	0.84		0.80			0.38	
170			0.69	0.84		0.80			0.39	
175			0.70	0.86		0.82			0.40	
180			0.71	0.88		0.83			0.40	

FIGURE 5.14.4: Ci/Co FOR CALCIUM MONTMORILLONITE NCIKEL

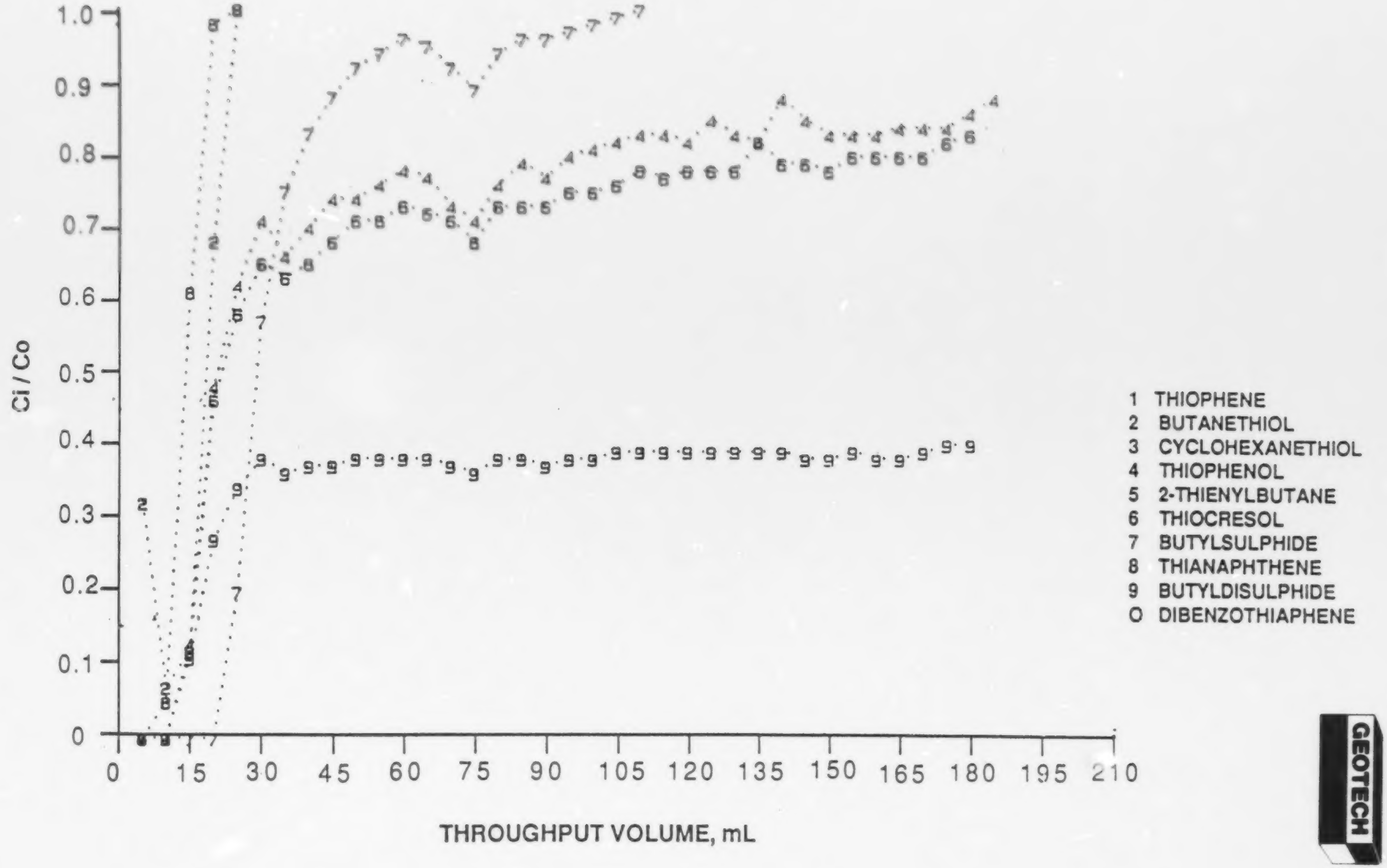


TABLE 5.14.5 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Calcium Montmorillonite Zinc

Sorbent Weight: 15.77 g   Column Bed Volume: 5.7 mL   Flowrate: 0.42 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.2	0	0	0	0	0	0	0	0	0
10	0.29	0	0	0	0.21	0	0.14	0.17	0.18	0.18
15	0.60	0	0.19	0	0.76	0	0.64	0.71	0.76	0.73
20	0.94	0.39	0.56	0	0.97	0	0.88	0.95	0.94	0.92
25	0.98	0.56	0.72	0.24	0.98	0.18	0.91	0.96	0.94	0.94
30	1.0	0.67	0.85	0.44	1.0	0.35	1.0	1.0	1.0	1.0
35		0.75	0.82	0.52		0.41				
40		0.79	0.85	0.60		0.49				
45		0.82	0.92	0.70		0.59				
50		0.84	0.89	0.71		0.62				
55		0.86	0.91	0.74		0.66				
60		0.90	0.92	0.76		0.67				
65		0.96	0.99	0.83		0.74				
70		1.0	1.0	0.92		0.83				
75				1.0		0.92				
80						1.0				

FIGURE 5. 14. 5: Ci/Co FOR CALCIUM MONTMORILLONITE ZINC

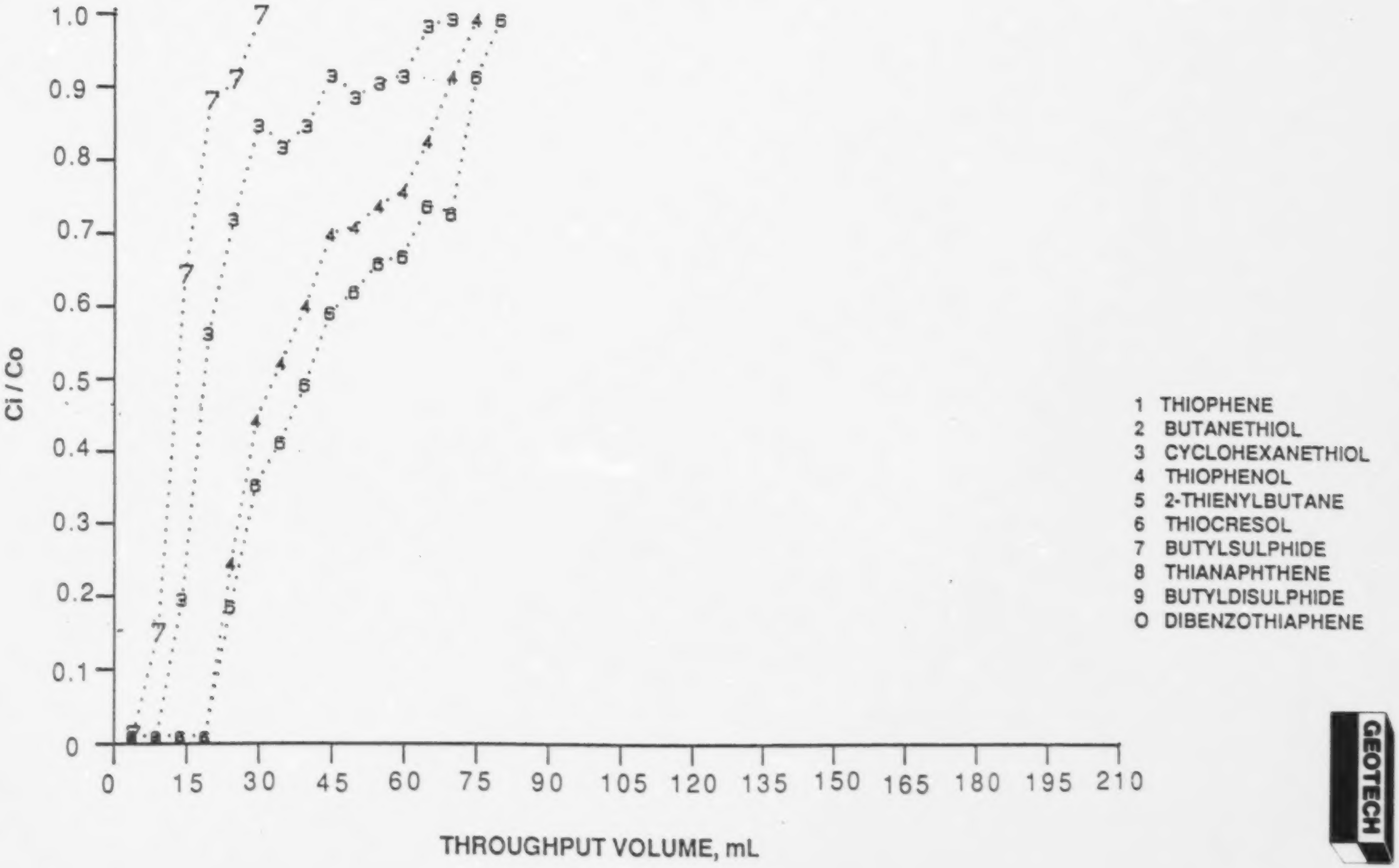


TABLE 5.15.1 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Calcium Montmorillonite Chlorhydrol

Sorbent Weight: 10.09 g   Column Bed Volume: 7.9 mL   Flowrate: 0.67 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.35	0.31	0	0	0	0	0	0	0	0
10	0.37	0.29	0	0.03	0.32	0.04	0.04	0.22	0.18	0.26
15	0.64	0.09	0.32	0.27	0.80	0.37	0.52	0.73	0.70	0.77
20	0.88	0.60	0.76	0.55	0.90	0.56	0.87	0.89	0.85	0.91
25	0.98	0.90	0.84	0.63	0.90	0.59	0.89	0.90	0.86	0.91
30	1.0	1.0	0.88	0.66	0.92	0.62	0.91	0.91	0.89	0.93
35			0.87	0.66	0.91	0.62	0.91	0.91	0.89	0.92
40			0.88	0.67	0.92	0.64	0.92	0.92	0.90	0.94
45			0.89	0.68	0.92	0.64	0.92	0.92	0.90	0.94
50			0.85	0.60	0.90	0.55	0.91	0.92	0.83	0.93
55			0.82	0.55	0.88	0.47	0.90	0.92	0.80	0.93
60			0.85	0.61	0.91	0.61	0.91	0.92	0.89	0.93
65			0.89	0.68	0.92	0.66	0.92	0.92	0.92	0.94
70			0.89	0.69	0.91	0.66	0.92	0.91	0.91	0.93
75			0.89	0.71	0.91	0.67	0.92	0.92	0.91	0.93
80			0.88	0.69	0.91	0.66	0.91	0.91	0.90	0.92
85			0.89	0.70	0.91	0.67	0.92	0.92	0.91	0.93
90			0.89	0.70	0.91	0.68	0.91	0.92	0.91	0.93
95			0.89	0.72	0.91	0.68	0.92	0.92	0.91	0.93
100			0.90	0.72	0.92	0.69	0.92	0.92	0.93	0.94
105			0.91	0.73	0.93	0.70	0.93	0.93	0.94	0.94
110			0.92	0.75	0.94	0.71	0.95	0.94	0.94	0.95
115			0.90	0.72	0.91	0.70	0.92	0.92	0.93	0.94

COMMENTS:

Values remain essentially constant through the duration of the test.

GEOTECH

FIGURE 5.15.1: Ci/Co FOR CALCIUM MONTMORILLONITE CHLORHYDROL

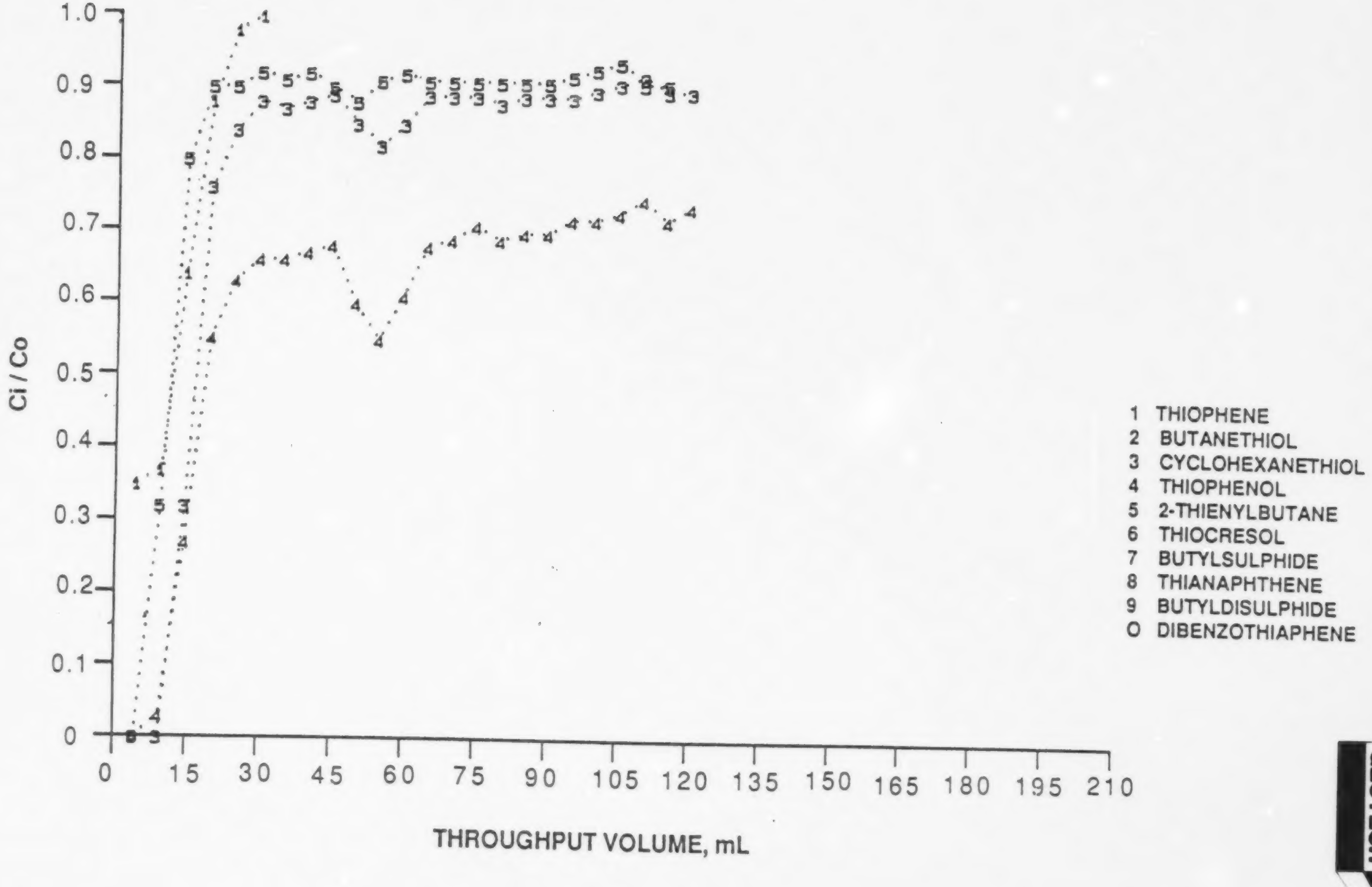


TABLE 5.15.2 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Calcium Montmorillonite Chlorhydrol Copper

Sorbent Weight: 12.52 g Column Bed Volume: 7.2 mL Flowrate: 0.58 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.32	0.06	0	0.03	0	0	0	0	0	0
10	0.42	0.30	0	0.03	0.13	0	0	0.11	0.06	0.09
15	0.73	0.07	0	0	0.63	0	0	0.60	0.37	0.60
20	0.88	0.08	0	0	0.85	0	0	0.86	0.58	0.85
25	0.97	0.18	0	0	0.88	0	0	0.90	0.67	0.89
30	0.89	0.07	0	0.03	0.88	0	0	0.94	0.70	0.90
35	1.0	0.19	0	0.02	0.91	0	0	0.96	0.74	0.93
40		0.18	0	0	0.90	0	0	0.94	0.75	0.93
45		0.08	0	0.03	0.89	0	0	0.91	0.74	0.91
50		0.27	0	0.03	0.91	0	0	0.95	0.77	0.93
55		0.19	0	0	0.90	0	0	0.93	0.78	0.93
60		0.27	0	0.02	0.94	0	0.03	0.98	0.79	0.94
65		0.07	0	0	0.90	0	0.04	0.93	0.79	0.93
70		0.07	0	0	0.89	0	0.05	0.91	0.78	0.93
75		0.19	0	0	0.90	0	0.08	0.94	0.79	0.93
80		0.19	0	0	0.90	0	0.14	0.94	0.79	0.91
85		0.19	0	0	0.90	0	0.17	0.95	0.81	0.94
90		0.19	0	0	0.90	0	0.22	0.98	0.81	0.92
95		0.19	0	0	0.91	0	0.27	0.93	0.83	0.92
100		0.19	0	0	0.89	0	0.30	0.93	0.81	0.91
105		0.27	0	0	0.89	0	0.35	0.92	0.82	0.90
110		0.27	0	0	0.89	0	0.38	0.93	0.83	0.92
115		0.27	0	0	0.91	0	0.43	0.96	0.85	0.93
120		0.22	0	0	0.89	0	0.46	0.93	0.84	0.91
125		0.27	0	0	0.91	0	0.49	0.94	0.86	0.93
130		0.27	0	0	0.91	0	0.52	0.91	0.85	0.91

TABLE 5.15.2 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Calcium Montmorillonite Chlorhydrol Copper

Sorbent Weight: 12.52 g Column Bed Volume: 7.2 mL Flowrate: 0.58 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
135		0.27	0	0	0.91	0	0.54	0.93	0.85	0.90
140		0.28	0	0	0.90	0	0.57	0.94	0.88	0.91
145		0.20	0	0	0.91	0	0.60	0.94	0.89	0.91
150		0.28	0	0	0.91	0	0.62	0.94	0.89	0.91
155		0.20	0	0	0.94	0	0.67	0.96	0.93	0.94
160		0.30	0	0	0.91	0	0.67	0.95	0.93	0.93
165		0.20	0	0	0.89	0	0.67	0.93	0.89	0.91
170		0.28	0	0	0.90	0	0.69	0.94	0.90	0.91

FIGURE 5. 15. 2: Ci/Co FOR CALCIUM MONTMORILLONITE CHLORHYDROL COPPER

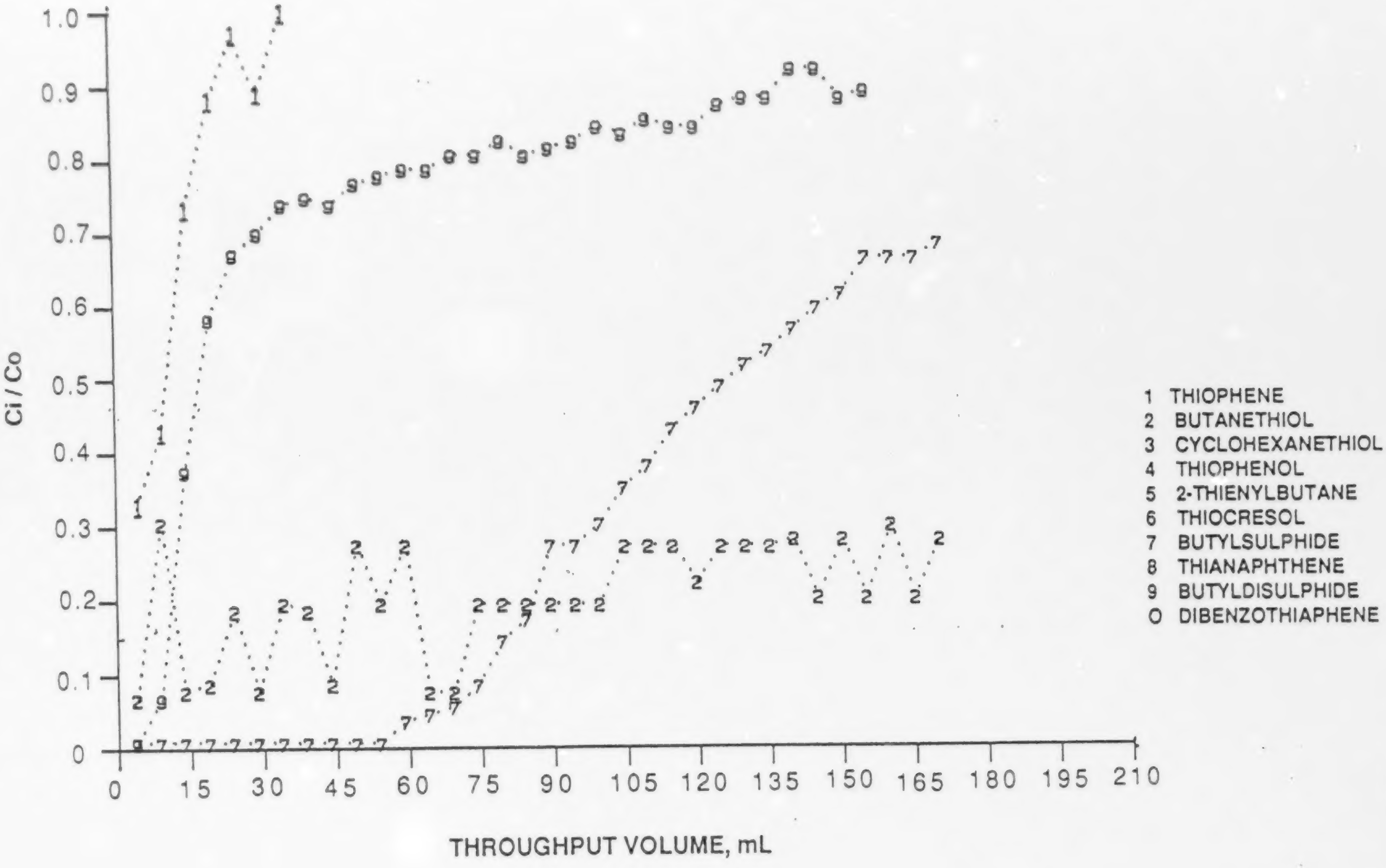


TABLE 5.15.3 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Calcium Montmorillonite Chlorhydrol Iron (III)

Sorbent Weight: 11.72 g Column Bed Volume: 7.0 mL Flowrate: 0.58 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.34	0.31	0	0.05	0	0	0	0	0	0
10	0.36	0.30	0	0.05	0.05	0	0	0.11	0	0.11
15	0.62	0.28	0	0.04	0.18	0	0	0.58	0.22	0.59
20	0.84	0.28	0	0	0.45	0	0	0.85	0.44	0.85
25	0.92	0.27	0	0	0.74	0	0.30	0.95	0.62	0.98
30	0.91	0.28	0	0	0.83	0	0.28	0.97	0.81	0.99
35	0.93	0.28	0	0	0.88	0	1.0	0.98	0.87	1.0
40	0.94	0.28	0	0	0.86	0		0.96	1.0	
45	0.92	0.08	0	0	0.87	0		0.97		
50	0.96	0.13	0.09	0	0.88	0		0.96		
55	0.93	0.17	0.17	0.04	0.90	0		0.97		
60	0.94	0.46	0.25	0.06	0.89	0		0.94		
65	0.94	0.57	0.31	0.09	0.89	0		0.95		
70	0.96	0.68	0.37	0.12	0.91	0.04		0.97		
75	0.96	0.74	0.41	0.16	0.91	0.05		0.96		
80	0.95	0.77	0.43	0.18	0.90	0.06		0.95		
85	0.92	0.81	0.46	0.21	0.91	0.08		0.96		
90	0.96	0.84	0.47	0.25	0.91	0.09		0.96		
95	0.97	0.86	0.48	0.26	0.91	0.09		0.96		
100	0.96	0.89	0.50	0.30	0.92	0.11		0.97		
105	0.97	0.91	0.51	0.31	0.91	0.12		0.96		
110	0.98	0.92	0.52	0.33	0.91	0.13		0.96		
115	0.95	0.93	0.53	0.34	0.92	0.15		0.94		
120	0.94	1.0	0.53	0.33	0.90	0.18		0.93		
125	0.98		0.55	0.35	0.92	0.19		0.97		
130	1.0		0.55	0.35	0.91	0.19		0.95		

TABLE 5.15.3 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Calcium Montmorillonite Chlorhydrol Iron (III)

Sorbent Weight: 11.72 g Column Bed Volume: 7.0 mL Flowrate: 0.58 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
135			0.55	0.36	0.90	0.20		0.91		
140			0.56	0.37	0.90	0.21		1.0		
145			0.57	0.38	0.91	0.22				
150			0.57	0.39	0.90	0.22				
155			0.57	0.40	0.90	0.24				
160			0.59	0.42	0.92	0.25				
165			0.59	0.43	0.90	0.26				
170			0.60	0.44	0.91	0.28				
175			0.60	0.42	0.91	0.30				

FIGURE 5.15.3: Ci/Co FOR CALCIUM MONTMORILLONITE CHLORHYDROL IRON (III)

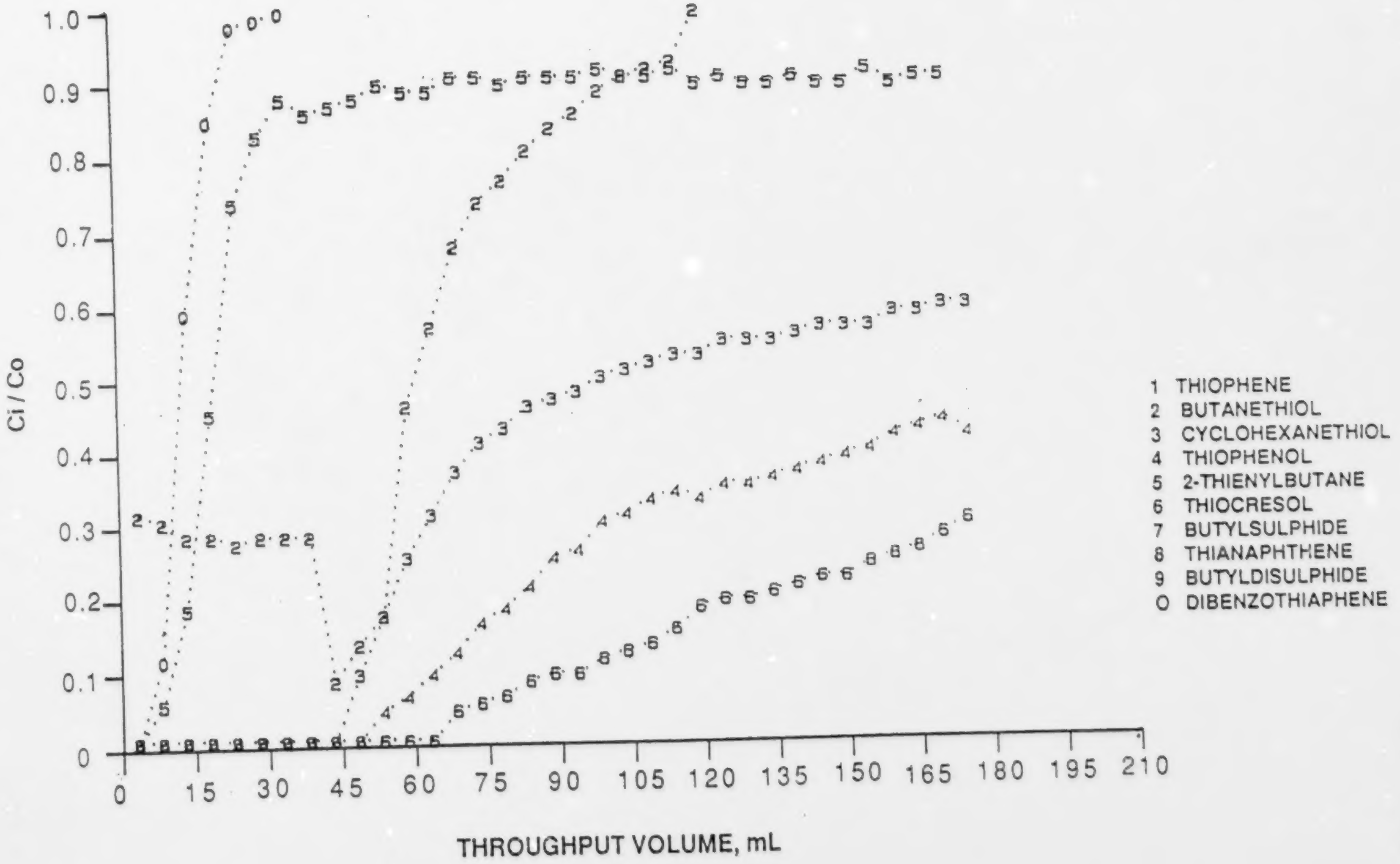


TABLE 5.15.4 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Calcium Montmorillonite Chlorhydrol Mercury

Sorbent Weight: 15.43 g Column Bed Volume: 5.4 mL Flowrate: 0.42 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.16	0.05	0	0.05	0	0	0	0	0	0
10	0.29	0.08	0.09	0.05	0.26	0	0.18	0.21	0.24	0.22
15	0.59	0.39	0.48	0.10	0.70	0.08	0.63	0.67	0.68	0.68
20	0.80	0.62	0.79	0.31	0.96	0.27	0.92	0.94	0.94	0.94
25	0.87	0.73	0.94	0.51	1.0	0.43	1.0	1.0	1.0	1.0
30	0.87	0.76	0.98	0.62		0.54				
35	0.74	0.74	0.78	0.51		0.45				
40	0.91	0.80	1.0	0.70		0.62				
45	0.90	0.80		0.72		0.66				
50	0.91	0.81		0.75		0.68				
55	0.86	0.78		0.74		0.67				
60	0.92	0.82		0.77		0.70				
65	0.94	0.96		0.79		0.73				
70	0.93	0.79		0.80		0.75				
75	0.84	0.81		0.76		0.71				
80	0.87	0.84		0.80		0.75				
85	0.89	0.88		0.83		0.78				
90	0.92	0.91		0.87		0.82				
95	0.92	0.81		0.88		0.83				
100	0.89	0.79		0.90		0.85				
105	0.90	0.89		0.87		0.83				
110	0.90	0.89		0.87		0.83				
115	0.83	0.87		0.87		0.83				
120	0.90	0.92		0.95		0.90				
125	0.85	0.86		0.90		0.86				
130	0.89	0.89		0.89		0.86				
135	0.90	0.90		0.89		0.86				
140	0.91	0.91		0.90		0.86				
145	0.89	0.89		0.91		0.86				

FIGURE 5.15.4: Ci/Co FOR CALCIUM MONTMORILLONITE CHLORHYDROL MERCURY

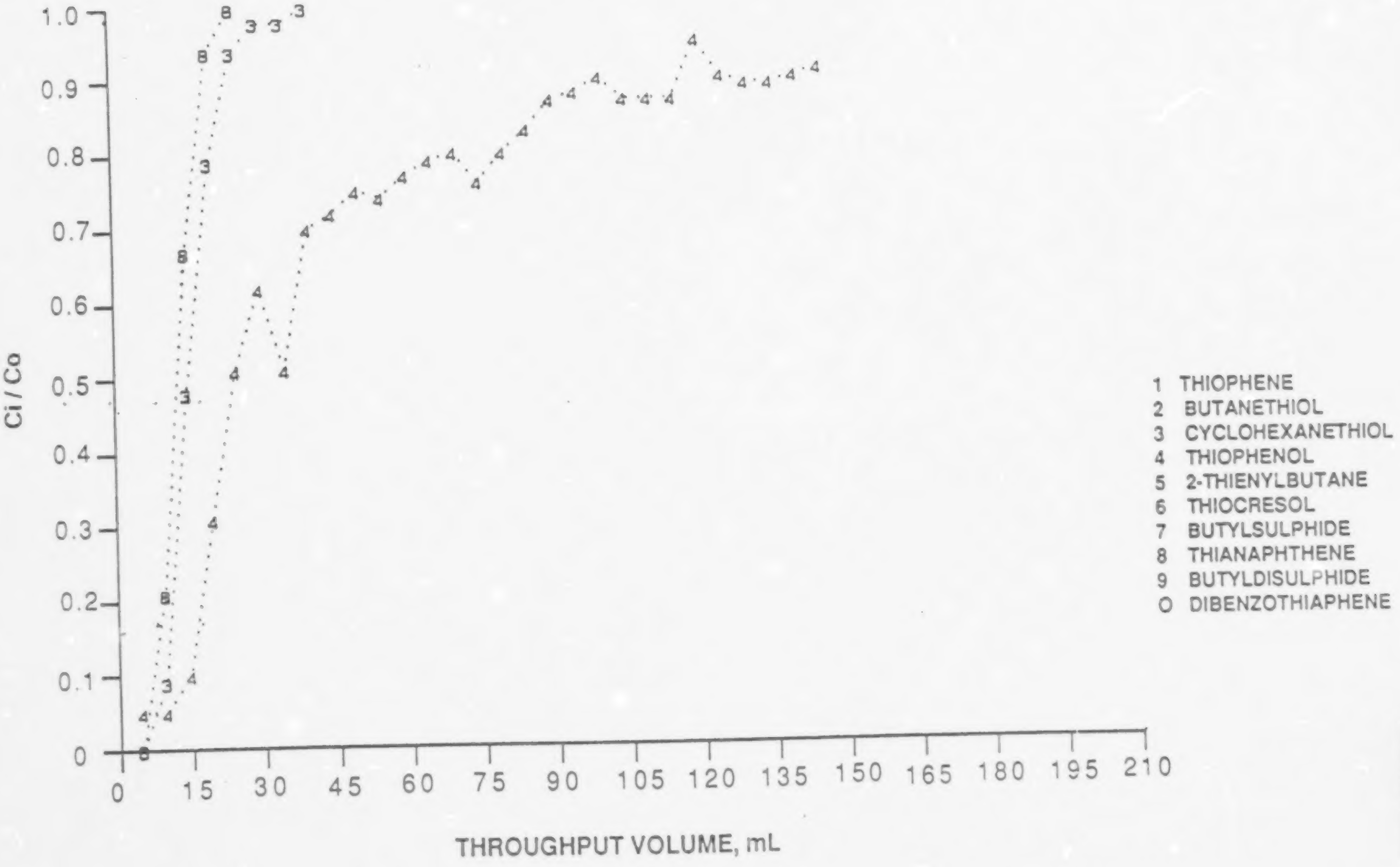


TABLE 5.15.5 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Calcium Montmorillonite Chlorhydrol Nickel

Sorbent Weight: 12.28 g   Column Bed Volume: 7.6 mL   Flowrate: 0.58 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.31	0.28	0	0.04	0	0	0	0	0	0
10	0.35	0.09	0.04	0.04	0.11	0	0.05	0.12	0.11	0.12
15	0.62	0.51	0.38	0.23	0.61	0.19	0.52	0.67	0.49	0.67
20	0.87	0.92	0.68	0.52	0.89	0.46	0.89	0.94	0.64	0.90
25	0.91	1.0	0.76	0.66	0.94	0.60	0.95	0.98	0.67	0.93
30	0.89		0.78	0.72	0.96	0.67	0.97	1.0	0.68	0.95
35	0.90		0.81	0.79	0.99	0.74	1.0		0.71	1.0
40	0.88		0.81	0.81	0.98	0.76			0.70	
45	0.93		0.81	0.81	0.96	0.76			0.70	
50	0.94		0.83	0.84	0.98	0.80			0.71	
55	0.93		0.83	0.85	0.98	0.81			0.71	
60	0.86		0.90	0.94	1.0	0.91			0.80	
65	0.92		0.83	0.86		0.82			0.72	
70	0.93		0.83	0.86		0.83			0.73	
75	0.95		0.79	0.83		0.78			0.96	
80	0.98		0.80	0.84		0.80			0.97	
85	1.0		0.80	0.83		0.80			0.97	
90			0.81	0.85		0.82			0.98	
95			0.80	0.84		0.80			0.97	
100			0.82	0.86		0.82			0.99	
105			0.82	0.86		0.82			0.99	
110			0.82	0.87		0.83			1.0	
115			0.82	0.87		0.83				
120			0.82	0.87		0.84				
125			0.82	0.87		0.83				
130			0.82	0.87		0.84				

TABLE 5.15.5 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Calcium Montmorillonite Chlorhydrol Nickel

Sorbent Weight: 12.28 g Column Bed Volume: 7.6 mL Flowrate: 0.58 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
135			0.83	0.88		0.84				
140			0.82	0.87		0.84				
145			0.83	0.88		0.85				
150			0.84	0.88		0.84				
155			0.86	0.90		0.88				
160			0.85	0.90		0.86				
165			0.84	0.88		0.85				
170			0.83	0.88		0.85				
175			0.84	0.88		0.85				

FIGURE 5.15.5: Ci/Co FOR CALCIUM MONTMORILLONITE CHLORHYDROL NICKEL

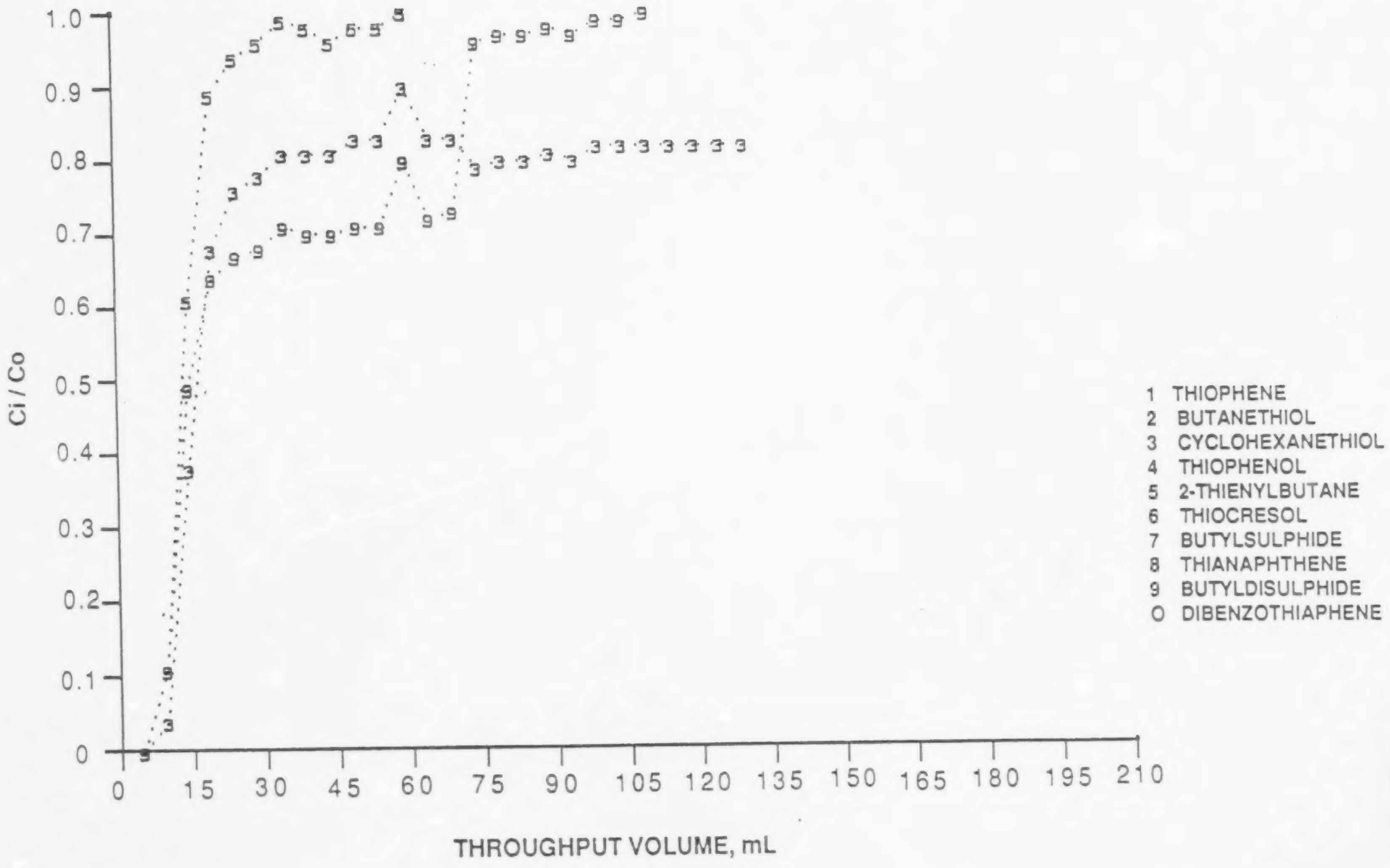


TABLE 5.15.6 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Calcium Montmorillonite Chlorhydrol Zinc

Sorbent Weight: 15.50 g Column Bed Volume: 6.4 mL Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.16	0.05	0	0.05	0	0	0	0	0	0
10	0.29	0.08	0.09	0.05	0.25	0	0.18	0.21	0.24	0.22
15	0.59	0.39	0.49	0.10	0.71	0.08	0.63	0.67	0.68	0.68
20	0.80	0.62	0.79	0.31	0.96	0.27	0.91	0.94	0.94	0.94
25	0.87	0.73	0.93	0.51	1.0	0.43	1.0	1.0	1.0	1.0
30	0.87	0.76	0.98	0.62		0.54				
35	0.73	0.74	0.78	0.51		0.45				
40	0.91	0.80	1.0	0.70		0.62				
45	0.90	0.80		0.72		0.66				
50	0.91	0.81		0.75		0.68				
55	0.86	0.78		0.74		0.68				
60	0.93	0.82		0.77		0.70				
65	0.93	0.96		0.79		0.73				
70	0.93	0.79		0.80		0.75				
75	0.84	0.81		0.75		0.71				
80	0.86	0.84		0.80		0.75				
85	0.88	0.87		0.85		0.89				
90	0.92	0.91		0.87		0.82				
95	0.91	0.81		0.88		0.83				
100	0.87	0.79		0.89		0.85				
105	0.88	0.83		0.88		0.84				
110	0.89	0.89		0.87		0.83				
115	0.83	0.87		0.87		0.83				
120	0.89	0.92		0.95		0.90				
125	0.85	0.86		0.89		0.86				
130	0.89	0.89		0.89		0.86				
135	0.66	0.68		0.74		0.73				
140	0.91	0.91		0.90		0.86				
145	0.89	0.89		0.91		0.86				

FIGURE 5.15.6: Ci/Co FOR CALCIUM MONTMORILLONITE CHLORHYDROL ZINC

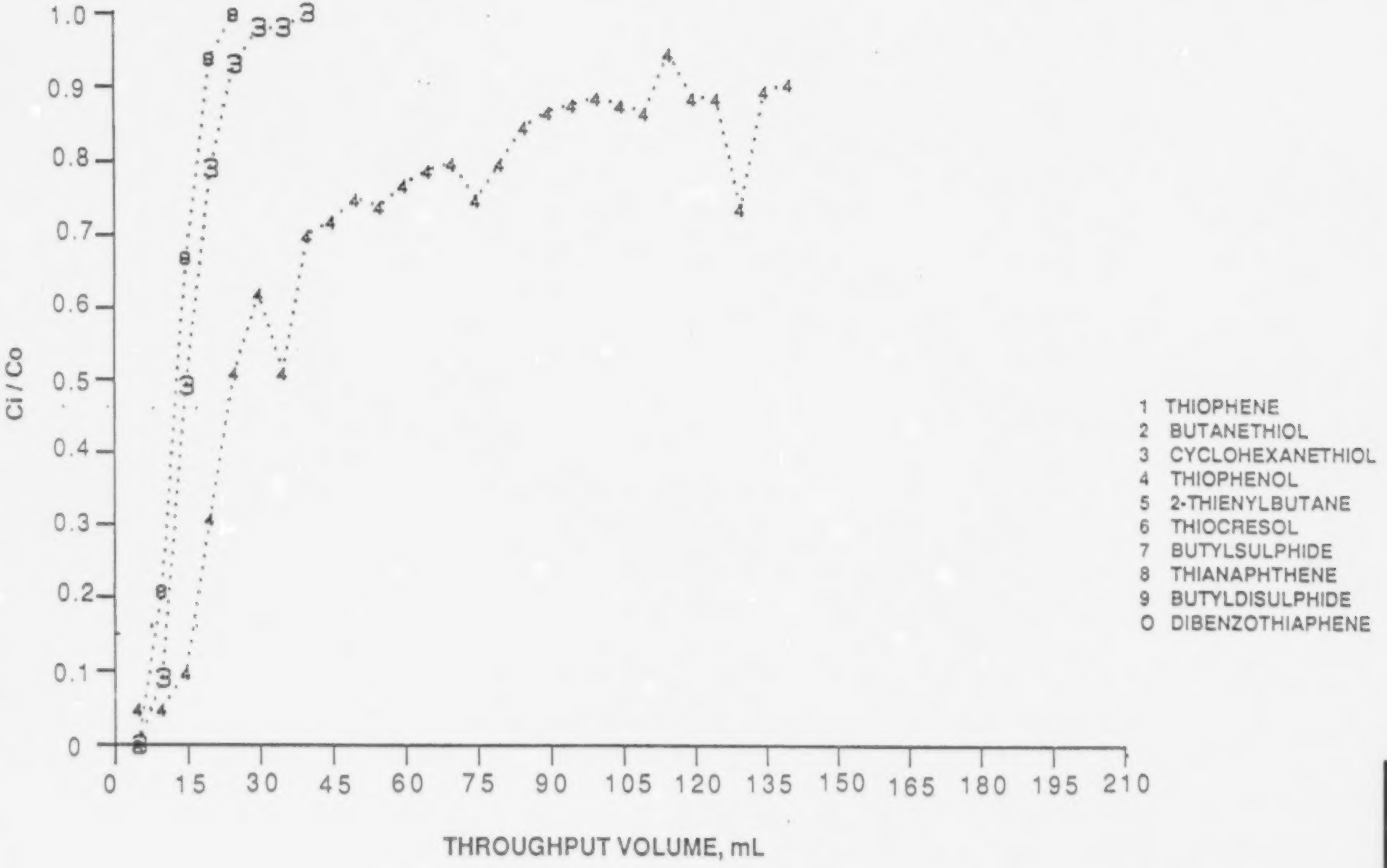


TABLE 5.16.1 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Zeolite X-13 Calcium @ 300°C

Sorbent Weight: 8.64 g Column Bed Volume: 6.5 mL Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.35	0.05	0	0.05	0	0	0	0	0	0
10	0.38	0.08	0.03	0.04	0.05	0	0.05	0.05	0	0.04
15	0.71	0.61	0.59	0.58	0.61	0.55	0.61	0.61	0.61	0.60
20	0.92	0.95	0.96	0.94	0.96	0.94	0.95	0.95	0.95	0.95
25	0.91	0.97	0.99	0.98	0.97	0.97	0.99	0.99	0.99	0.99
30	0.97	1.0	1.0	0.97	0.97	0.98	0.98	0.99	0.99	0.99
35	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

FIGURE 5.16.1: Ci/Co FOR ZEOLITE X-13 CALCIUM @ 300 C

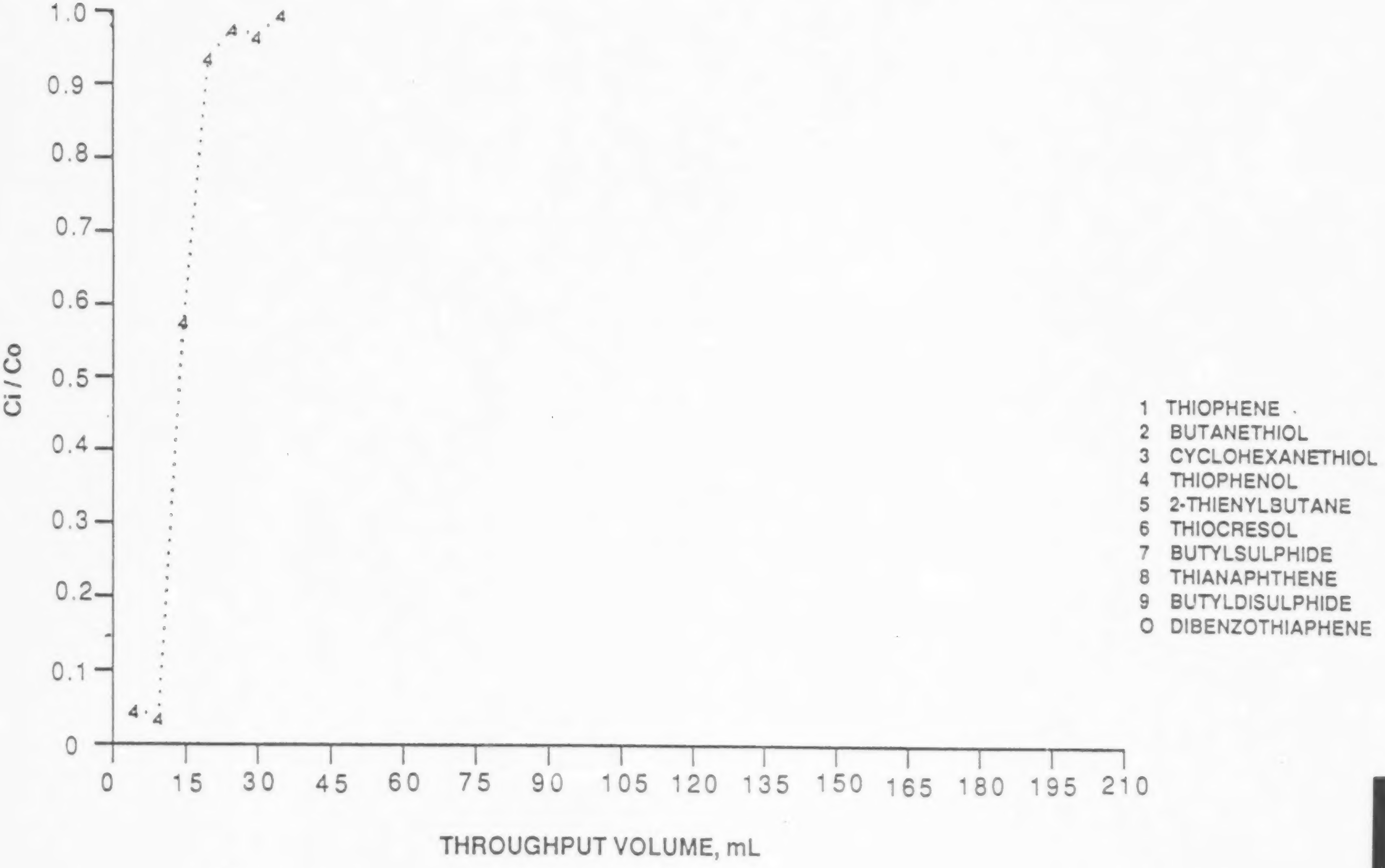


TABLE 5.16.2 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Zeolite X-13 Copper @ 300°C

Sorbent Weight: 9.51 g   Column Bed Volume: 7.3 mL   Flowrate: 0.58 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.35	0.29	0	0.05	0	0	0	0	0	0
10	0.33	0.27	0	0	0.02	0	0	0	0	0.02
15	0.66	0.27	0	0	0.48	0	0.42	0.46	0.56	0.46
20	0.92	0.26	0	0	0.86	0	0.83	0.84	1.0	0.84
25	0.98	0.26	0	0	0.92	0	0.89	0.91		0.91
30	0.99	0.27	0	0	0.93	0	0.90	0.91		0.92
35	1.0	0.27	0	0	0.94	0	0.94	0.95		0.95
40		0.26	0	0	0.95	0	0.92	0.93		0.94
45		0.26	0	0	0.95	0	0.92	0.93		0.93
50		0.26	0	0	0.95	0	0.92	0.93		0.94
55		0.26	0	0	0.99	0	0.96	0.97		0.97
60		0.27	0	0.04	0.95	0	0.92	0.93		0.94
65		0.26	0	0.04	0.94	0	0.92	0.92		0.94
70		0.27	0	0.04	0.94	0	0.92	0.93		0.93
75		0.26	0	0.03	0.95	0	0.92	0.94		0.94
80		0.18	0	0	0.95	0	0.92	0.93		0.94
85		0.19	0	0	0.93	0	0.91	0.92		0.93
90		0.26	0	0	0.94	0	0.92	0.93		0.93
95		0.19	0	0	0.92	0	0.90	0.91		0.93
100		0.26	0	0	0.93	0	0.92	0.93		0.93
105		0.26	0	0	0.94	0	0.91	0.92		0.93
110		0.27	0	0	0.93	0	0.92	0.92		0.93
115		0.19	0	0	0.93	0	0.91	0.91		0.93
120		0.25	0	0.04	0.92	0	0.90	0.91		0.92
125		0.17	0	0	0.91	0	0.89	0.91		0.91
130		0.19	0	0	0.92	0	0.90	0.91		0.92
135		0.18	0	0	0.92	0	0.90	0.91		0.9
140		0.26	0	0	0.92		0.91	0.91		0.9

FIGURE 5.16.2: Ci/Co FOR ZEOLITE X-13 COPPER @ 300 C

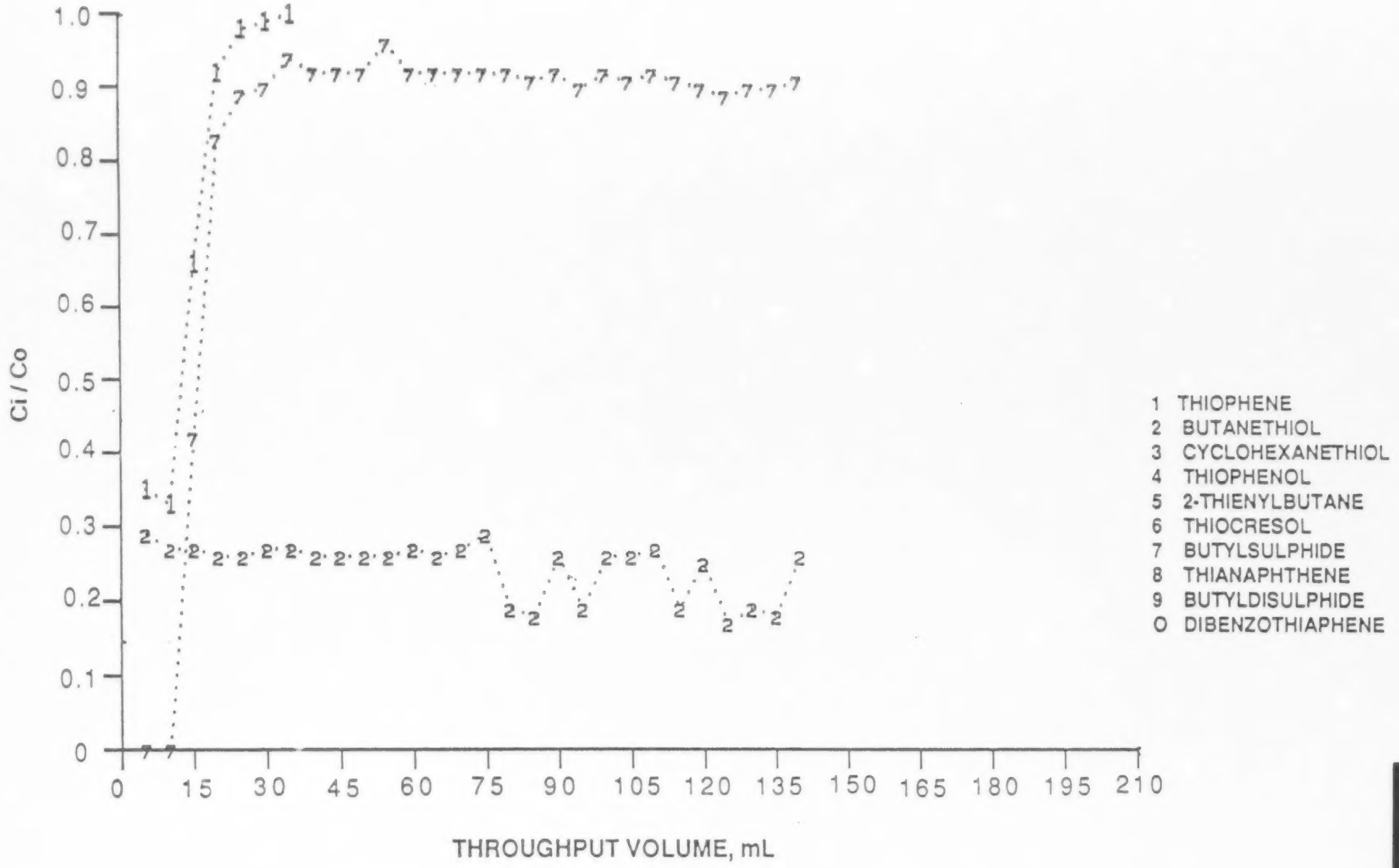


TABLE 5.16.3 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Zeolite X-13 Hydrogen @ 300°C

Sorbent Weight: 5.80 g Column Bed Volume: 7.8 mL Flowrate: 0.67 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.34	0.29	0	0	0	0	0	0	0	0
10	0.34	0.29			0.03		0.02	0.02		0.02
15	0.61	0.58	0.44	0.44	0.46	0.44	0.45	0.45	0.44	0.45
20	0.88	0.87	0.88	0.87	0.89	0.87	0.88	0.88	0.88	0.89
25	0.89	0.95	0.97	0.97	0.98	0.95	0.98	1.0	0.97	0.99
30	0.92	0.98	1.0	0.98	1.0	0.98	1.0	1.0	0.99	1.0
35	0.94	1.0		1.0		1.0			1.0	
40	0.94									
45	0.97									
50	1.0									

FIGURE 5.16.3: Ci/Co FOR ZEOLITE X-13 HYDROGEN @ 300 C

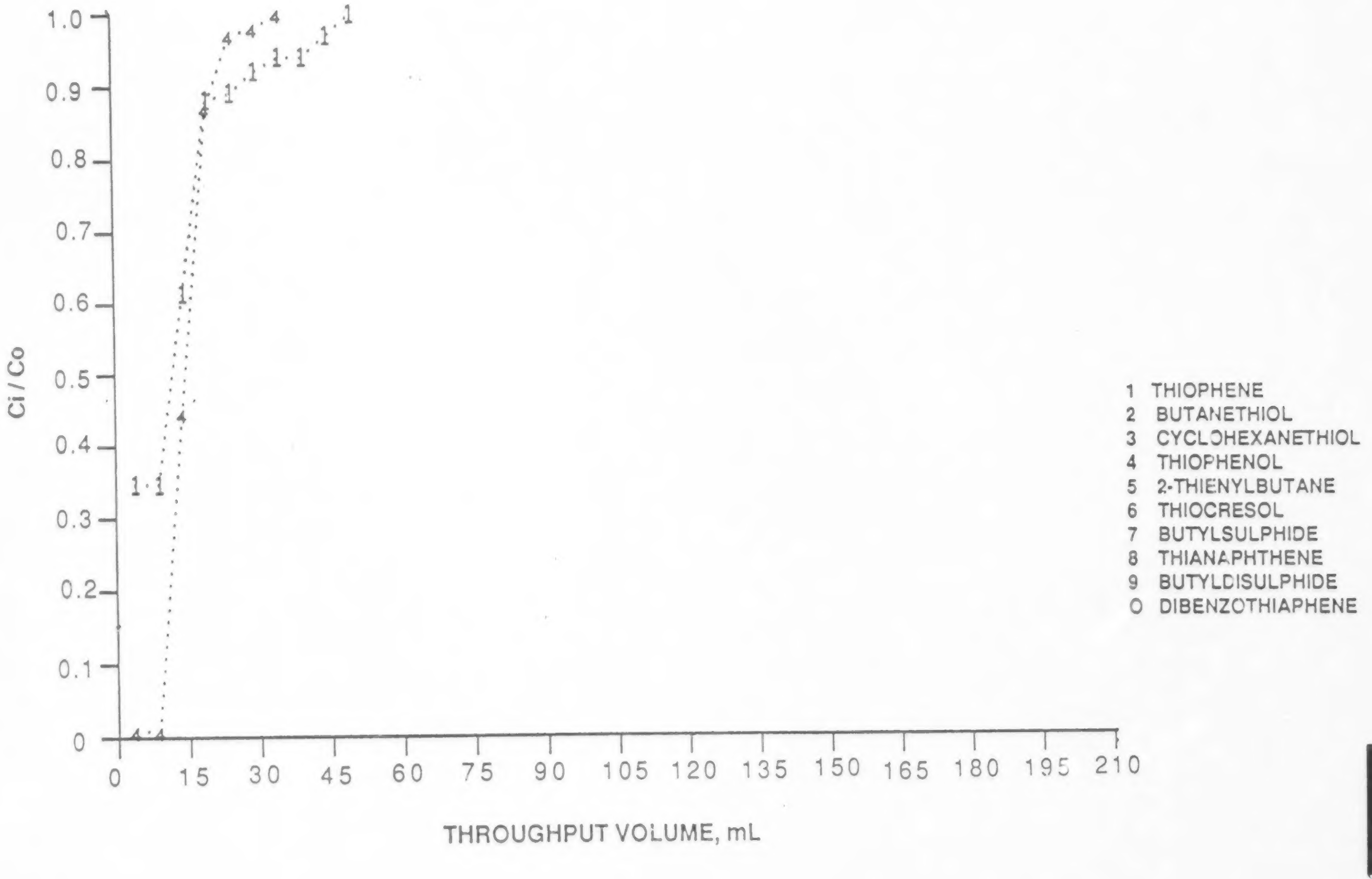


TABLE 5.16.4 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Zeolite X-13 Mercury @ 300°C

Sorbent Weight: 8.58 g Column Bed Volume: 6.7 mL Flowrate: 0.50 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.35	0.30	0	0.03	0	0	0	0	0	0
10	0.36	0.32	0	0.04	0	0	0.04	0.04	0	0.04
15	0.68	0.59	0.56	0.51	0.59	0.54	0.58	0.58	0.58	0.58
20	0.92	0.97	0.92	0.88	0.92	0.90	0.92	0.91	0.92	0.91
25	0.91	1.0	0.98	0.98	0.98	0.97	0.98	0.98	0.99	0.97
30	1.0		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

FIGURE 5.16.4: C_i/C_o FOR ZEOLITE X-13 MERCURY @ 300 C

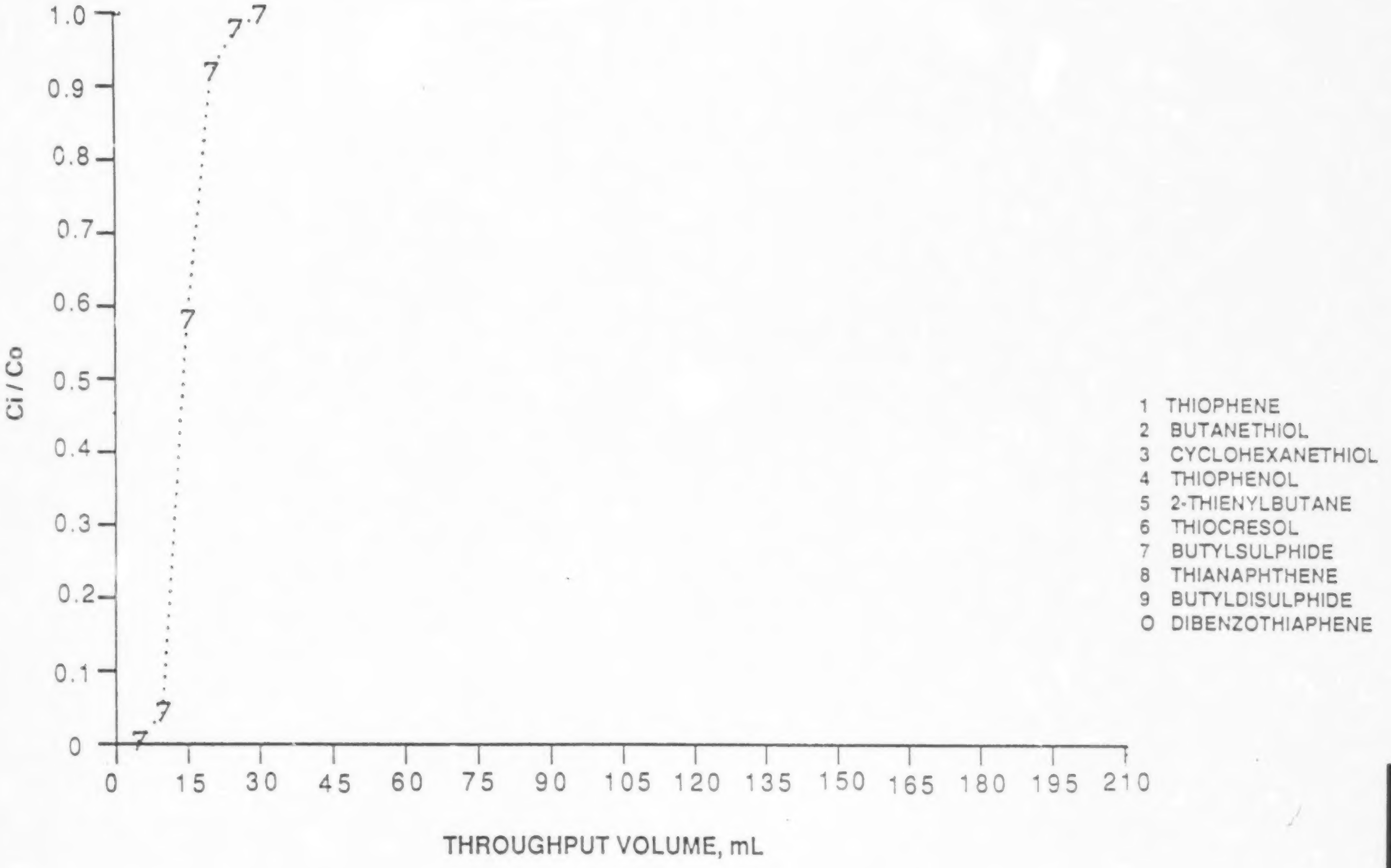


TABLE 5.16.5 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Zeolite X-13 Zinc

Sorbent Weight: 8.76 g Column Bed Volume: 6.9 mL Flowrate: 0.58 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.32	0.27	0	0	0	0	0	0	0	0.03
10	0.36	0.29		0.03						0.02
15	0.67	0.85	0.48	0.46	0.52	0.44	0.52	0.52	0.53	0.53
20	0.90	0.91	0.93	0.94	0.92	0.92	0.91	0.91	0.93	0.93
25	0.95	0.97	0.97	0.97	0.98	0.97	0.98	0.98	0.98	0.98
30	0.94	0.97	0.99	1.0	0.99	0.99	1.0	0.99	0.98	0.99
35	0.96	0.99	0.98		0.98	0.98		0.99	0.98	0.98
40	0.98	0.99	0.99		0.99	0.99		1.0	1.0	1.0
45	1.0	1.0	1.0		1.0	1.0				

FIGURE 5.16.5: Ci/Co FOR ZEOLITE X-13 ZINC @ 300 C

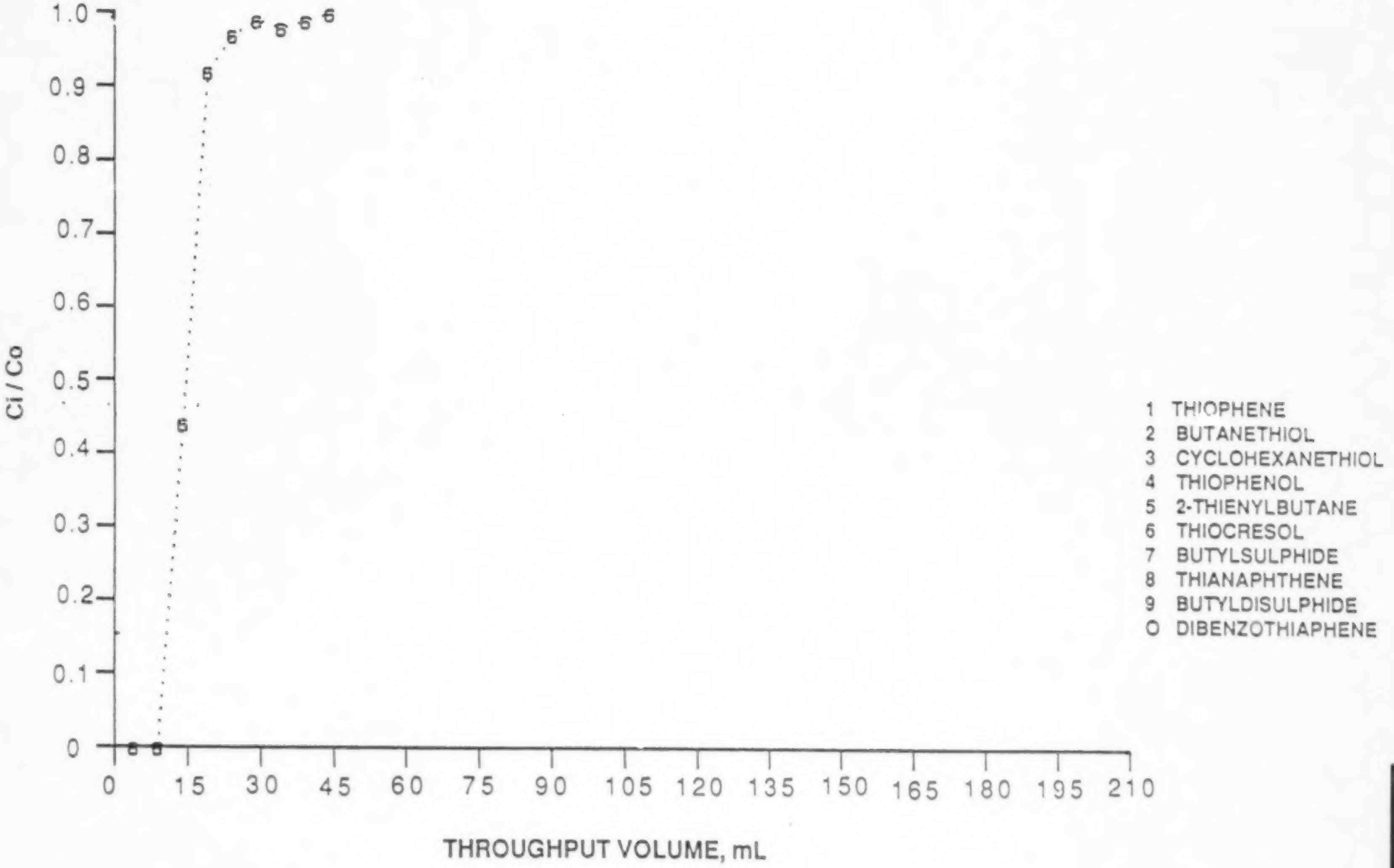


TABLE 5.16.6 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Zeolite X-13 Calcium @ 500°C

Sorbent Weight: 8.28 g   Column Bed Volume: 6.8 mL   Flowrate: 0.58 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.32	0	0	0.04	0	0	0	0	0	0
10	0.41	0.08	0.07	0.07	0.08	0.05	0.08	0.08	0.08	0.09
15	0.81	0.73	0.71	0.69	0.72	0.68	0.71	0.71	0.71	0.71
20	0.91	0.94	0.95	0.93	0.95	0.93	0.95	0.95	0.94	0.98
25	0.98	1.0	1.0	0.97	0.95	0.96	0.95	0.96	0.95	1.0
30	0.99			0.98	0.99	0.99	0.99	0.99	0.99	1.0
35	1.0									

FIGURE 5.16.6: C_i/C_o FOR ZEOLITE X-13 CALCIUM @ 500 C

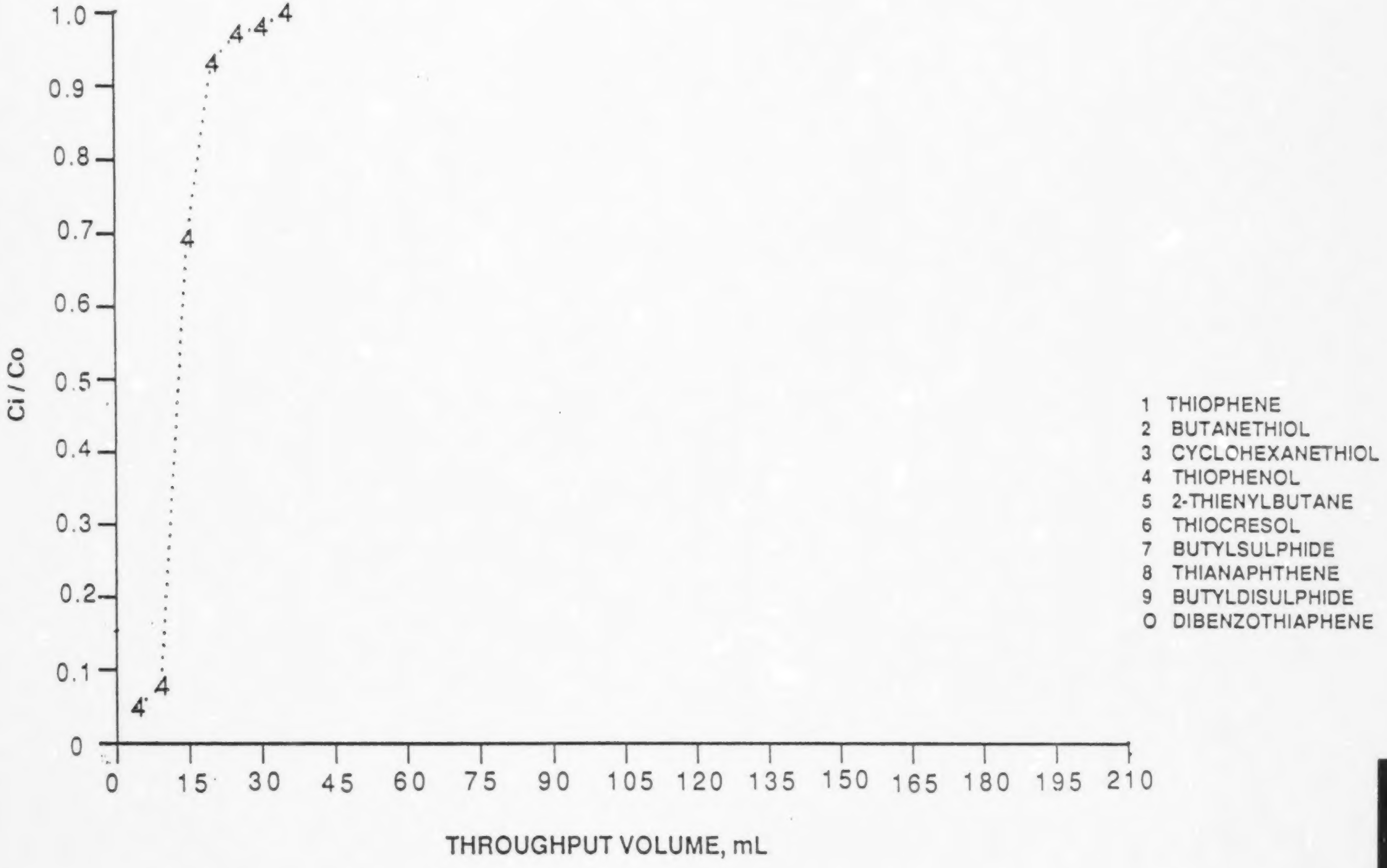


TABLE 5.16.7 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Zeolite X-13 Copper @ 500°C

Sorbent Weight: 9.13 g Column Bed Volume: 7.2 mL Flowrate: 0.58 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.31	0.07	0	0.05	0	0	0	0	0	0
10	0.33	0.27	0	0.05	0.04	0	0.03	0.03	0	0.03
15	0.69	0.10	0.14	0.04	0.58	0	0.57	0.57	0.65	0.56
20	0.86	0.79	0.90	0.60	0.95	0.56	0.94	0.94	0.95	0.93
25	0.90	0.87	0.94	0.78	0.97	0.75	0.97	0.97	0.98	0.98
30	0.91	0.91	0.97	0.83	1.0	0.81	1.0	1.0	1.0	1.0
35	0.91	0.91	0.98	0.86		0.83				
40	0.91	0.91	0.98	0.85		0.84				
45	0.94	0.92	0.97	0.86		0.84				
50	0.94	0.93	1.0	0.86		0.85				
55	0.88	0.91		0.88		0.87				
60	0.94	0.93		0.87		0.86				
65	0.94	0.94		0.88		0.88				
70	0.93	0.91		0.88		0.87				
75	0.90	0.88		0.84		0.84				
80	0.92	0.89		0.86		0.85				
85	0.90	0.90		0.86		0.85				
90	0.90	0.90		0.86		0.85				
95	0.90	0.89		0.86		0.86				
100	0.90	0.89		0.87		0.86				
105	0.85	0.87		0.89		0.89				
110	0.88	0.89		0.88		0.88				
115	0.91	0.91		0.88		0.88				
120	0.88	0.89		0.88		0.89				
125	0.91	0.90		0.88		0.90				
130	0.93	0.93		0.89		0.89				
135	0.90	0.91		0.90		0.91				
140	0.90	0.90		0.91		0.91				
145	0.93	0.92		0.89		0.88				
150	0.92	0.94		0.92		0.90				
155	0.92	0.91		0.90		0.90				
160	0.89	0.90		0.91		0.90				
165	0.91	0.91		0.94		0.91				

FIGURE 5.16.7: Ci/Co FOR ZEOLITE X-13 COPPER @ 500 C

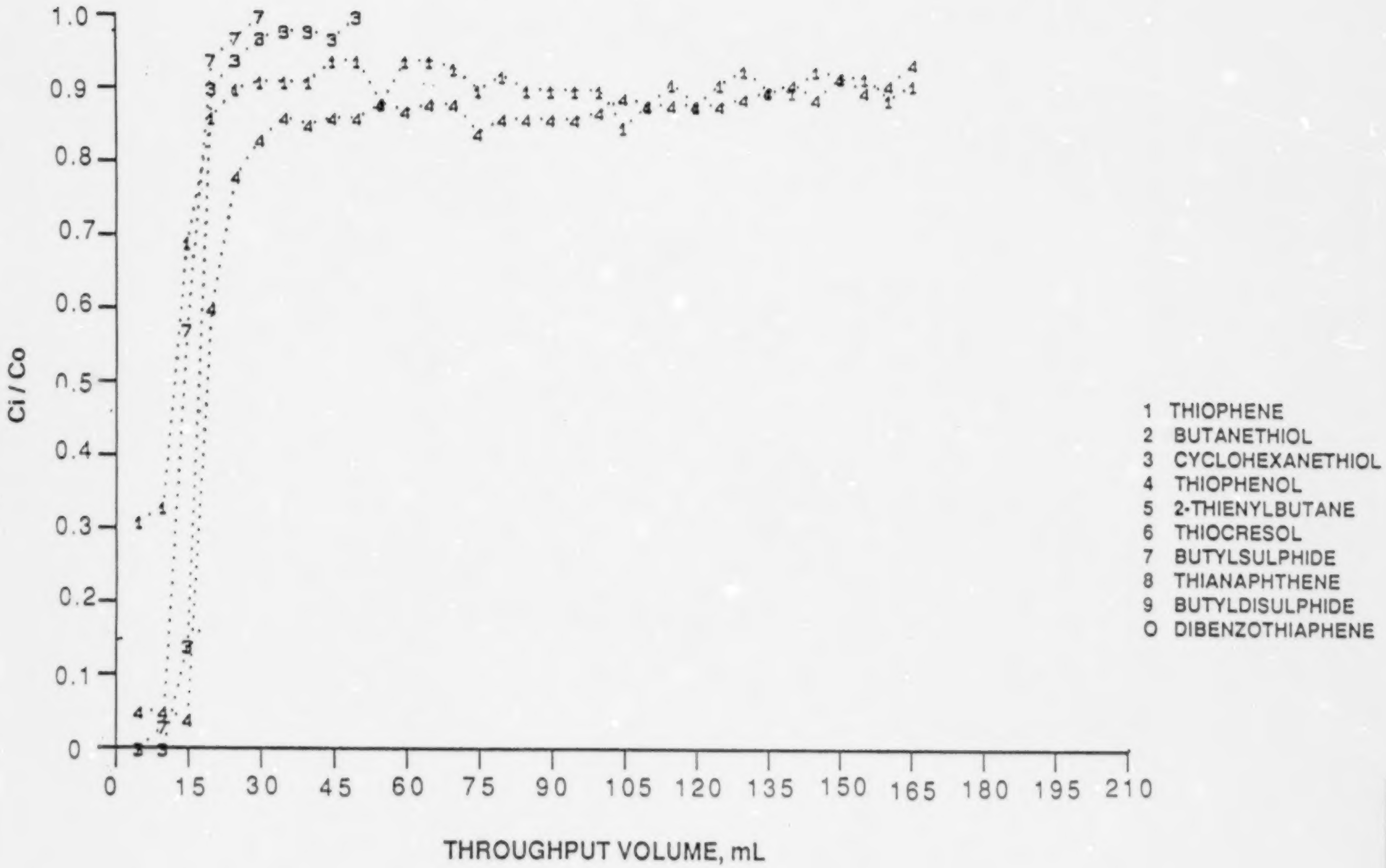


TABLE 5.16.8 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Zeolite X-13 Hydrogen @ 500°C

Sorbent Weight: 5.72 g Column Bed Volume: 7.4 mL Flowrate: 0.58 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.36	0.04	0	0.04	0	0	0	0	0	0
10	0.38	0.04	0	0.04	0	0	0	0	0	0
15	0.44	0.07	0.15	0.14	0.18	0.13	0.17	0.17	0.18	0.16
20	0.89	0.84	0.83	0.81	0.83	0.80	0.82	0.82	0.83	0.78
25	0.89	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	1.0
30	0.94	1.0		1.0		1.0	1.0	1.0	1.0	1.0
35	0.99									
40	1.0									

FIGURE 5. 16. 8:   Ci/Co FOR ZEOLITE Z-13 HYDROGEN @ 500 C

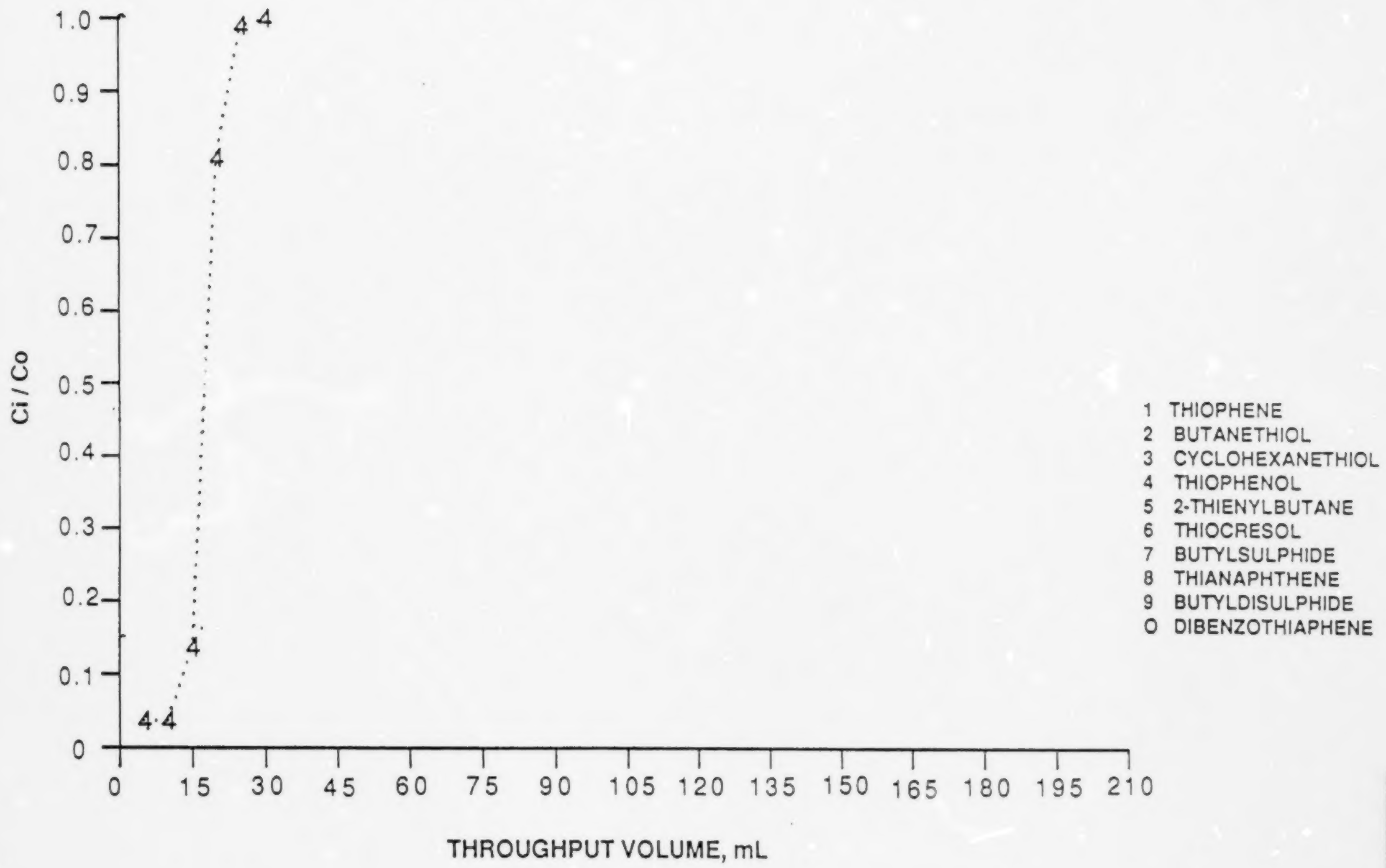


TABLE 5.16.9 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Zeolite X-13 Mercury @ 500°C

Sorbent Weight: 8.15 g Column Bed Volume: 6.9 mL Flowrate: 0.58 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.32	0.28	0	0	0	0	0	0	0	0
10	0.34	0.29	0	0.05	0.02	0	0.02	0.03	0	0.02
15	0.61	0.53	0.54	0.54	0.57	0.52	0.57	0.57	0.57	0.60
20	0.84	0.89	0.86	0.94	0.96	0.94	0.96	0.96	0.96	0.99
25	0.91	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
30	1.0	1.0								

FIGURE 5.16.9: Ci/Co FOR ZEOLITE X-13 MERCURY @ 500 C

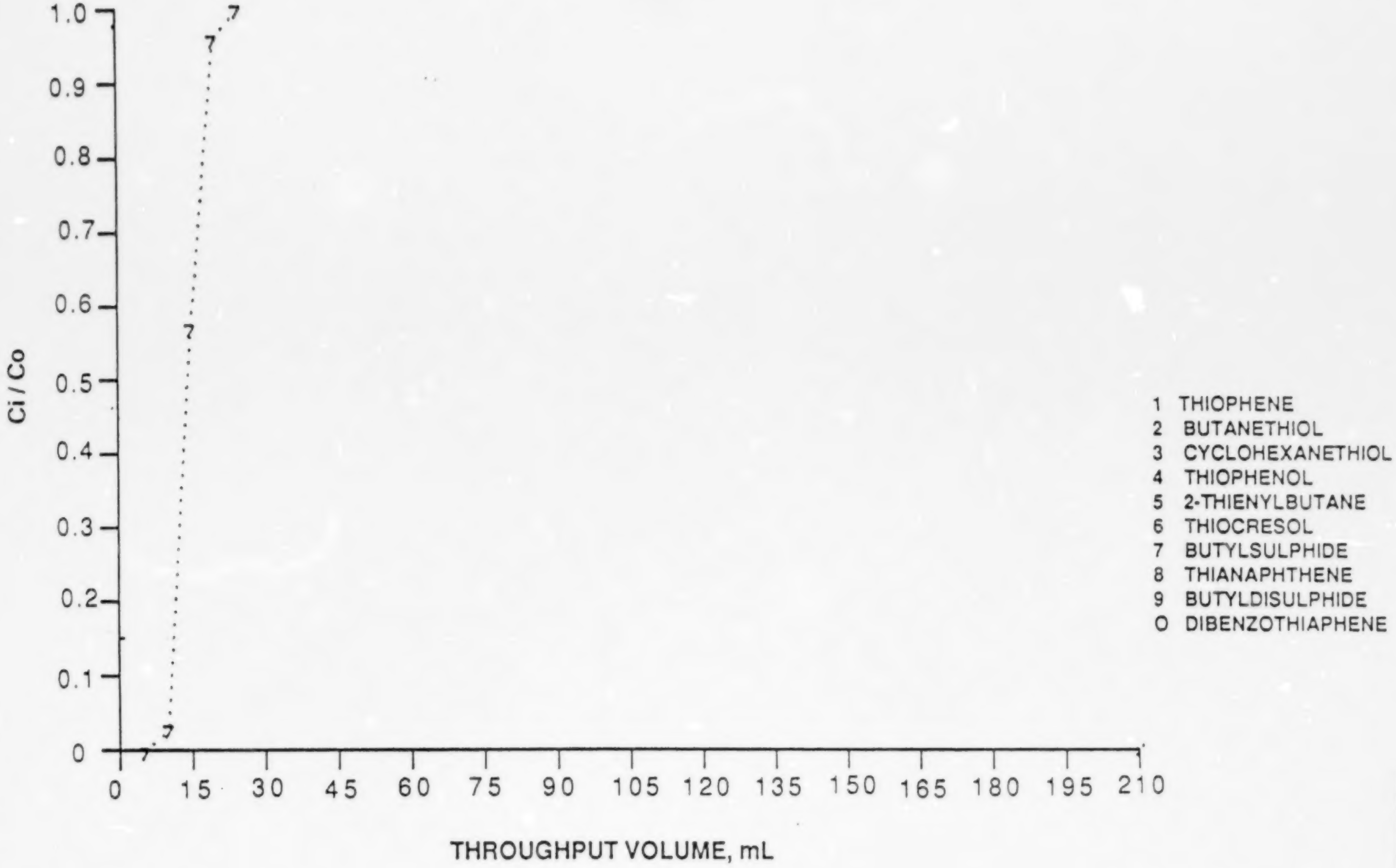


TABLE 5.16.10 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Zeolite X-13 Zinc @ 500°C

Sorbent Weight: 8.33 g Column Bed Volume: 7.3 mL Flowrate: 0.58 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.43	0.26	0	0.05	0	0	0	0	0	0
10	0.45	0.27	0	0.04	0.03	0	0	0	0	0
15	0.67	0.51	0.53	0.45	0.56	0.45	0.55	0.55	0.56	0.54
20	0.85	0.88	0.94	0.92	0.94	0.92	0.94	0.95	0.94	0.95
25	0.88	0.93	0.99	0.98	0.99	0.98	0.99	1.0	1.0	1.0
30	0.89	0.95	1.0	1.0	1.0	1.0	1.0			
35	0.88	0.94								
40	0.88	0.94								
45	0.91	0.96								
50	0.88	0.95								
55	0.88	0.97								
60	0.91	0.96								
65	0.91	0.96								
70	0.90	0.96								
75	0.91	0.97								
80	0.94	0.98								
85	0.97	1.0								
90	1.0									

FIGURE 5.16.10: Ci/Co FOR ZEOLITE X-13 ZINC @ 500 C

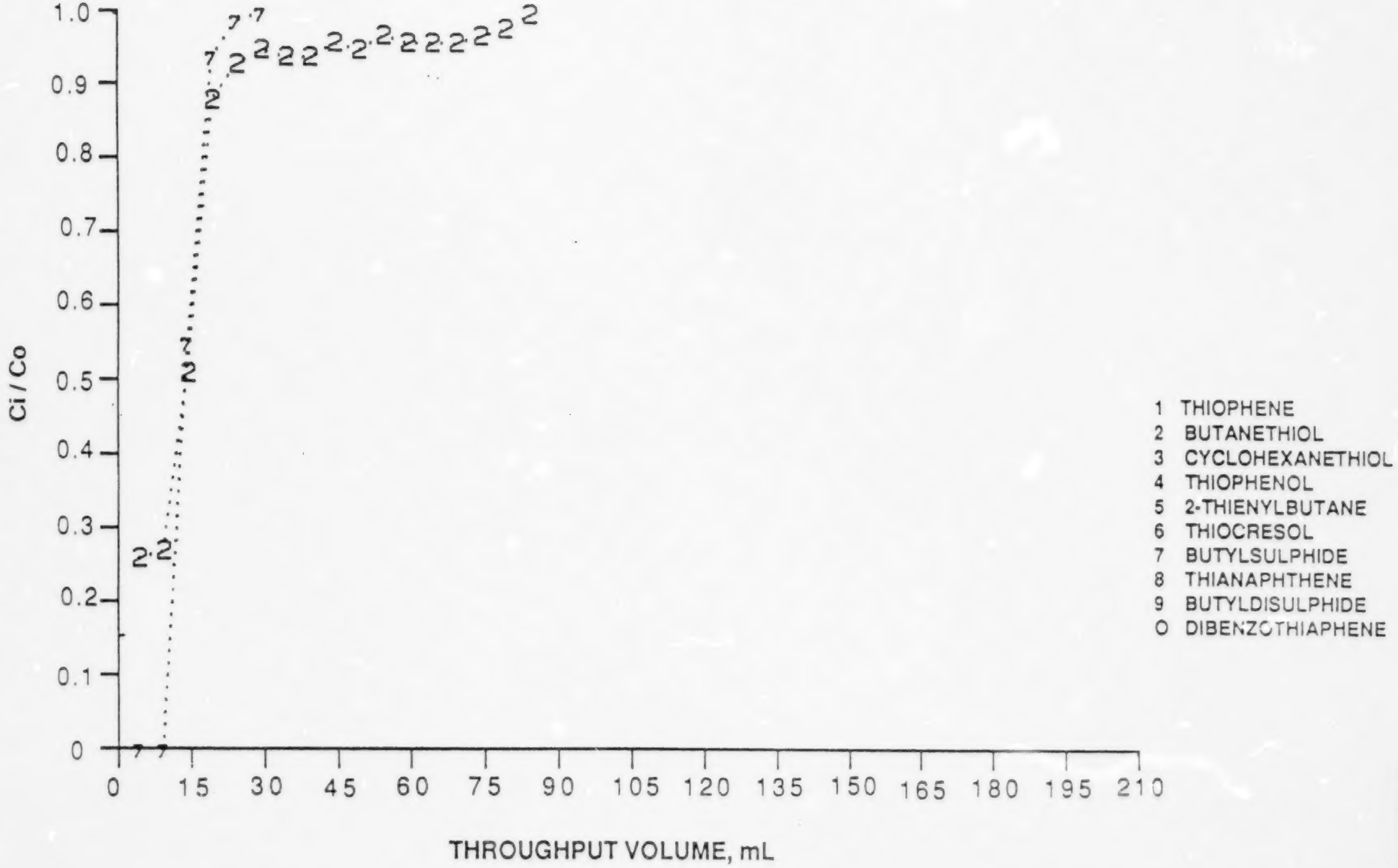


TABLE 5.17.1 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Charcoal 6-15 Mesh

Sorbent Weight: 5.94 g   Column Bed Volume: 7.1 mL   Flowrate: 0.58 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.48	0.26	0	0	0	0	0	0	0	0
10	0.49	0.27	0	0.04	0.04	0	0.03	0.02	0	0
15	0.67	0.29	0.12	0.04	0.44	0	0.45	0.15	0.51	0.01
20	0.88	0.14	0.49	0.03	0.83	0	0.83	0.51	0.99	0.01
25	0.95	0.39	0.65	0.04	0.93	0	0.92	0.74	1.0	0.02
30	0.95	0.49	0.72	0.04	0.96	0.03	0.96	0.84		0.02
35	0.95	0.53	0.77	0.03	0.99	0.04	0.98	0.91		0.03
40	0.96	0.58	0.79	0.03	0.99	0.05	0.99	0.94		0.05
45	0.97	0.60	0.79	0.03	0.99	0.07	0.98	0.96		0.08
50	1.0	0.63	0.81	0.03	1.0	0.07	1.0	1.0		0.13
55		0.64	0.83	0.03		0.08				0.18
60		0.67	0.84	0.08		0.07				0.24
65		0.68	0.84	0.03		0.06				0.29
70		0.71	0.88	0.04		0.05				0.34
75		0.73	0.88	0.04		0.04				0.38
80		0.76	0.89	0.05		0.04				0.43
85		0.77	0.90	0.04		0.04				0.47
90		0.80	0.91	0.04		0.04				0.34
95		0.80	0.91	0.04		0.04				0.54
100		0.82	0.91	0.04		0.04				0.57
105		0.80	0.90	0.04		0.06				0.60
110		0.82	0.92	0.04		0.06				0.63
115		0.83	0.93	0.04		0.06				0.65
120		0.83	0.92	0.04		0.06				0.66
125		0.83	0.91	0.11		0.08				0.69
130		0.85	0.94	0.04		0.07				0.71
135		0.85	0.94	0.09		0.06				0.72
140		0.85	0.94	0.04		0.07				0.74
145		0.87	0.96	0.04		0.07				0.76
150		0.86	0.94	0.04		0.08				0.76
155		0.88	0.95	0.12		0.09				0.78
160		0.88	0.96	0.13		0.09				0.79
165		0.86	0.96	0.13		0.09				0.80
170		0.88	0.94	0.04		0.10				0.81
175		0.89	0.94	0.04		0.11				0.82

FIGURE 5.17.1: Ci/Co FOR ACTIVATED CARBON 6-15 MESH

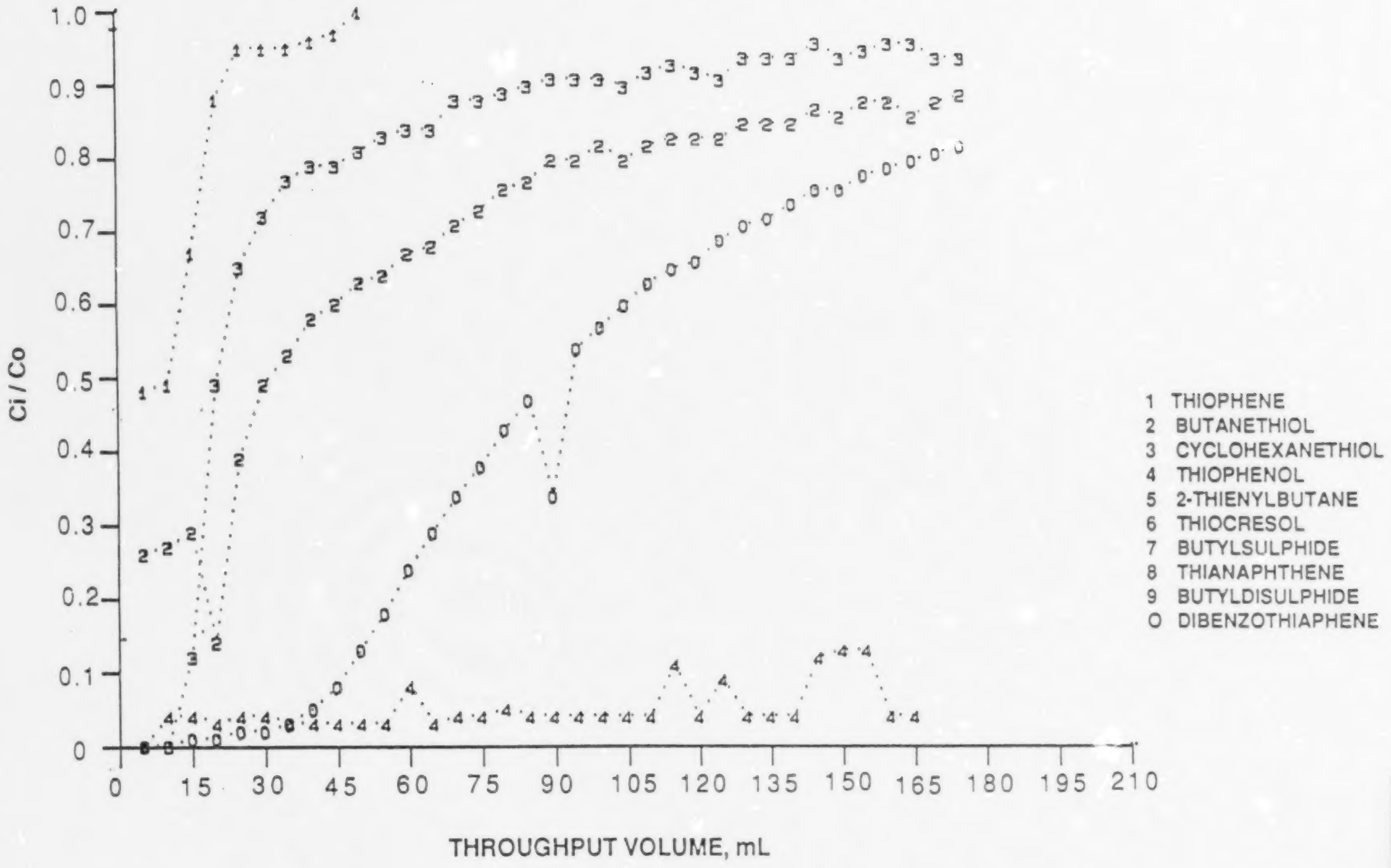


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TABLE 5.17.2 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Charcoal 50-200 Mesh

Sorbent Weight: 4.40 g Column Bed Volume: 9.4 mL Flowrate: 0.75 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
5	0.46	0.26	0	0	0	0	0	0	0	0
10	0.77	0.26	0	0	0	0	0	0	0	0
15	0.53	0.26	0	0	0.14	0	0.14	0	0.11	0
20	0.84	0.06	0	0	0.76	0	0.76	0.25	0.91	0
25	0.97	0.06	0.37	0	0.93	0	0.92	0.83	1.0	0
30	0.97	0.36	0.58	0	0.95	0	0.94	0.97		0.03
35	0.98	0.49	0.71	0	0.98	0	0.97	1.0		0.06
40	1.0	0.52	0.71	0	0.94	0	0.93			0.08
45		0.62	0.77	0	0.97	0	0.97			0.08
50		0.62	0.77	0	0.96	0	0.95			0.08
55		0.61	0.76	0	0.96	0.13	0.96			0.07
60		0.66	0.78	0	0.96	0.09	0.96			0.07
65		0.72	0.83	0	0.96	0.07	0.96			0.06
70		0.73	0.85	0	0.97	0.07	0.97			0.11
75		0.76	0.88	0	0.99	0.06	0.98			0.28
80		0.82	0.90	0	0.99	0.07	0.99			0.50
85		0.80	0.89	0	1.0	0.08	1.0			0.68
90		0.83	0.89	0		0.07				0.79
95		0.86	0.91	0		0.06				0.86
100		0.88	0.96	0.08		0.07				0.94
105		0.85	0.89	0.04		0.08				0.92
110		0.85	0.88	0.14		0.11				0.92
115		0.83	0.89	0.03		0.12				0.94
120		0.86	0.90	0.09		0.12				0.94
125		0.89	0.92	0.15		0.11				0.95
130		0.85	0.91	0.03		0.12				0.95
135		0.92	0.94	0.16		0.12				0.96
140		0.93	0.97	0.03		0.12				0.98
145		0.92	0.94	0.04		0.13				0.96
150		0.94	0.95	0.19		0.14				0.98
155		0.93	0.93	0.04		0.15				0.97
160		0.94	0.95	0.04		0.16				0.97
165		0.95	0.93	0.05		0.18				0.97

TABLE 5.17.2 Ci/Co AS A FUNCTION OF THROUGHPUT VOLUME

Sorbent: Charcoal 50-200 Mesh

Sorbent Weight: 4.40 g Column Bed Volume: 9.4 mL Flowrate: 0:75 mL/min

Throughput Volume (mL)	Thiophene	Butane Thiol	Cyclohexane Thiol	Thio Phenol	2-Thienyl Butane	Thio Cresol	Butyl Sulphide	Thia Naphthene	Butyl Disulphide	Dibenzo Thiaphene
170		0.95	0.91	0.28		0.19				0.96
175		0.94	0.92	0.03		0.20				0.97
180		0.93	0.93	0.24		0.17				0.97
185		0.94	0.97	0.03		0.15				0.98
190		0.97	0.96	0.04		0.16				0.98
195		0.95	0.95	0.04		0.16				0.97
200		0.95	0.95	0.04		0.16				0.97
205		0.94	0.96	0.04		0.16				0.98
210		0.96	0.95	0.04		0.17				0.98

FIGURE 5.17.2: Ci/Co FOR ACTIVATED CARBON 50-200 MESH

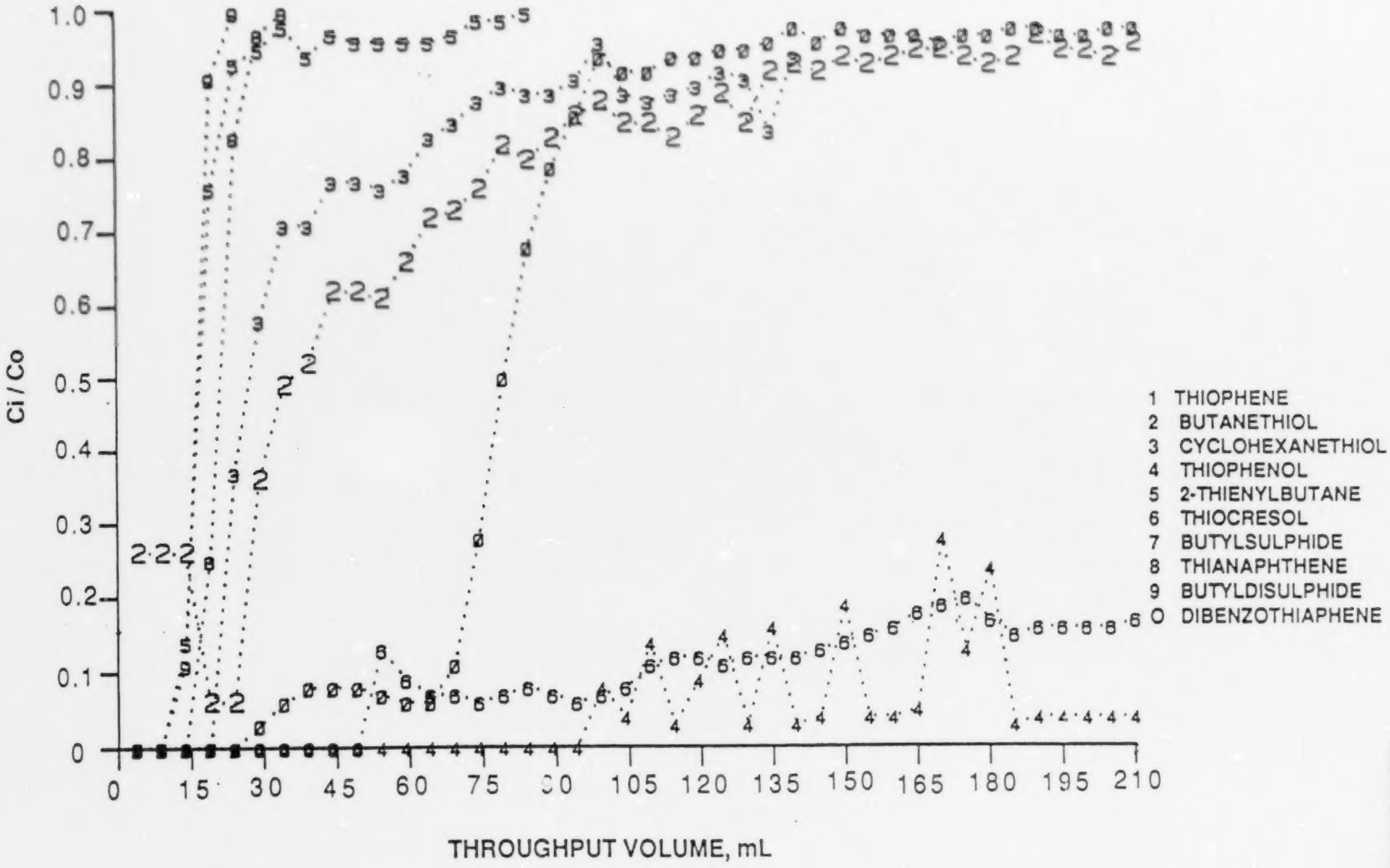

TABLE 5.18: SULPHUR LOADING ON THE SORBENTS

Sorbent	Sorbent Weight (g)	Total Sulphur (mgS)	Sulphur per Gram Sorbent (mgS/g)
Amberlite IRN-77	9.69	9.40	0.97
Amberlite IRN-78	7.95	48.97	6.16
Amberlite IR-124	10.35	9.20	0.89
Amberlite IR-130 C	9.91	6.84	0.69
Amberlite XAD-2	4.73	10.90	2.30
Amberlite XAD-7	4.14	12.77	3.08
Amberlite XAD-8	4.49	8.34	1.86
Amberlyst XN-1010			
Barium	8.22	11.57	1.41
Copper	7.90	54.61	6.92
Hydrogen	7.08	11.89	1.68
Iron	7.35	47.20	6.42
Lanthanum	7.66	6.77	0.88
Mercury	6.79	39.52	5.05
Nickel	7.14	10.50	1.47
Strontium	7.58	12.29	1.62
Titanium	7.50	13.04	1.74
Vanadium	7.52	15.54	2.07
Zinc	6.70	13.98	2.09
Amberlyst 15			
Barium	7.73	11.74	1.52
Copper	7.74	54.94	7.09
Iron	7.23	35.42	4.89
Hydrogen	6.79	12.34	1.82
Lanthanum	7.25	10.26	1.41
Mercury	7.34	13.12	1.79
Nickel	7.41	14.19	1.92
Strontium	7.60	11.70	1.54
Titanium	7.11	11.87	1.67
Vanadium	6.89	11.14	1.62
Zinc	7.62	18.16	2.38

TABLE 5.18: SULPHUR LOADING ON THE SORBENTS

Sorbent	Sorbent Weight (g)	Total Sulphur (mgS)	Sulphur per Gram Sorbent (mgS/g)
Attapulgite			
Copper	8.11	117.05	14.43
Iron	7.42	30.82	4.15
Mercury	8.24	36.53	4.43
Nickel	6.69	14.08	2.10
Zinc	8.47	15.86	1.87
Attpulgite Chlorhydrol	6.92	21.59	3.12
Copper	7.86	87.32	11.11
Iron	7.20	34.67	4.82
Mercury	7.12	16.95	2.38
Nickel	7.01	14.80	2.11
Zinc	6.95	15.65	2.25
Bentonite			
Copper	15.37	75.82	4.93
Iron	15.03	50.65	3.37
Nickel	15.01	12.99	0.87
Zinc	14.09	44.63	3.17
Bentonite Chlorhydrol			
Copper	15.10	72.10	4.77
Iron	14.86	37.98	2.56
Nickel	15.37	12.62	0.82
Zinc	15.18	18.75	1.24
Calcium Montmorillonite			
Copper	16.13	59.04	3.67
Iron	15.73		4.24
Mercury	10.37	22.28	2.15
Nickel	10.17	39.51	3.88
Zinc	15.77	16.93	1.07
Calcium Montmorillonite Chlorhydrol	10.09	27.88	2.76
Copper	12.52	81.87	6.54
Iron	11.72	64.12	5.47
Mercury	15.43	19.09	1.24
Nickel	12.28	19.83	1.62
Zinc	15.50	20.51	1.32
Zeolite X-13 @ 300°C			
Calcium	8.64	10.25	1.19
Copper	9.51	69.26	7.28
Hydrogen	5.80	11.16	1.92
Mercury	8.58	10.31	1.20
Zinc	8.76	11.00	1.25

TABLE 5.18: SULPHUR LOADING ON THE SORBENTS

Sorbent	Sorbent Weight (g)	Total Sulphur (mgS)	Sulphur per Gram Sorbent (mgS/g)
Zeolite X-13 @ 500°C			
Calcium	8.28	9.65	1.16
Copper	9.13	17.61	1.93
Hydrogen	5.72	15.14	2.56
Mercury	8.15	10.32	1.27
Zinc	8.33	11.15	1.34
Activated Carbon			
6-15 Mesh	5.94	50.72	8.54
50-200 Mesh	4.40	56.22	12.78